

04

~~III~~



~~DE~~ E 7.5 1 0.2.1 3

NASA CR-142399
ERIM 193300-59-F

Final Report

A COMPARISON OF ERTS-1 AND SLAR DATA FOR THE STUDY OF SURFACE WATER RESOURCES

M. LEONARD BRYAN
Radar and Optics Division

JANUARY 1975

"Made available under NASA sponsorship
in the interest of early and wide dis-
semination of Earth Resources Survey
Program information and without liability
for any use made thereof."

Original photography may be purchased from:
EROS Data Center
10th and Dakota Avenue
Sioux Falls, SD 57198

(E75-10213). COMPARISON OF ERTS-1 AND SLAR
DATA FOR THE STUDY OF SURFACE WATER
RESOURCES Final Report, 1 Jul. 1972 - 30
Aug. 1974 (Environmental Research Inst. of
Michigan) 102 p HC \$5.25 N75-21738
Unclas
CSCL 08H G3/43 00213

Prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Goddard Space Flight Center
Greenbelt, Maryland 20771
Contract No. NAS5-21783, Task IV
E. Sjzana, Project Manager

1072A

ENVIRONMENTAL
RESEARCH INSTITUTE OF MICHIGAN
FORMERLY WILLOW RUN LABORATORIES, THE UNIVERSITY OF MICHIGAN
BOX 618 • ANN ARBOR • MICHIGAN 48107

RECEIVED

FEB 03 1975

SIS/902.6

NOTICES

Sponsorship. The work reported herein was conducted by the Environmental Research Institute of Michigan for the National Aeronautics and Space Administration, Goddard Space Flight Center, Greenbelt, Maryland 20771 under Contract NAS5-21783, Task IV. Mr. E. Sijana is Project Manager.

Contracts and grants to the Institute for the support of sponsored research are administered through the Office of Contracts Administration.

Disclaimers. This report was prepared as an account of Government-sponsored work. Neither the United States, nor the National Aeronautics and Space Administration (NASA), nor any person acting on behalf of NASA:

- (A) Makes any warranty or representation, expressed or implied with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or
- (B) Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used above, "person acting on behalf of NASA" includes any employee or contractor of NASA, or employee of such contractor, to the extent that such employee or contractor of NASA or employee of such contractor prepares, disseminates, or provides access to any information pursuant to his employment or contract with NASA, or his employment with such contractor.

Availability Notice. Requests for copies of this report should be referred to:

National Aeronautics and Space Administration
Scientific and Technical Information Facility
P. O. Box 33
College Park, Maryland 20740

Final Disposition. After this document has served its purpose, it may be destroyed. Please do not return it to the Environmental Research Institute of Michigan.

Technical Report Documentation Page

1. Report No. NASA CR-ERIM 193300-59-F		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle A COMPARISON OF ERTS-1 AND SLAR DATA FOR THE STUDY OF WATER RESOURCES				5. Report Date January 1975	
				6. Performing Organization Code	
7. Author(s) M. Leonard Bryan				8. Performing Organization Report No. 193300-59-F	
9. Performing Organization Name and Address Environmental Research Institute of Michigan Radar and Optics Division P.O. Box 618 Ann Arbor, MI. 48107				10. Work Unit No. (TRAIS) Task IV	
				11. Contract or Grant No. NAS5-21783	
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Goddard Space Flight Center Greenbelt, Maryland 20771				13. Type of Report and Period Covered Final Report 1 July 1972 through 30 August 1974	
				14. Sponsoring Agency Code	
15. Supplementary Notes Mr. E. Sjazana was Project Manager and Dr. F. Quinn (National Oceanic and Atmospheric Agency, Detroit, Michigan) was Technical Monitor					
16. Abstract <p>This study was initially designed to study the types of data which could be obtained from two remote sensors with respect to freshwater ice in the upper Great Lakes. In order to accurately evaluate these data, and their comparability, it was necessary to identify a ground truth procedure which would be applicable. In addition, because it was envisioned that there would be a need for near real time interpretations of these data, the development of the rationale for preparing an interpretation key was emphasized. Consequently, although the SLAR was not operational in sufficient time to obtain remotely sensed data, both the ERTS and the SLAR ground truth procedures were initiated and developed to a degree which adequately demonstrated their validity for such interpretation work. The use of a small hand-held filtered radiometer for obtaining albedo from different ice and snow surfaces for use with the ERTS-1 data, and the utilization of a Q-meter and slotted-line waveguide for measuring electrical properties of ice for use in SLAR image interpretation, is demonstrated. An example of the application of these ground truth data for image interpretation is presented, especially with the ERTS-1 ground truth work.</p> <p>Additionally, both ERTS-1 and multiplexed SLAR were used to collect data over the Lake Erie shoreline of Monroe County, Michigan. During the data collection these areas were in flood, enabling us to compare the utility of both sensors for</p> <p style="text-align: right;">(continued)</p>					
17. Key Words Lake ice Radar Snow Microwave ground truth Coastal flooding Remote sensing ERTS (1)				18. Distribution Statement Initial distribution is listed at the end of this document.	
19. Security Classif. (of this report) UNCLASSIFIED		20. Security Classif. (of this page) UNCLASSIFIED		21. No. of Pages 104	
22. Price					

16. Abstract (continued)

identifying flooded lands, the land-water boundary and several types of non-flooded lands. In these cases, black and white infrared photography was the primary source of 'ground truth.'

The results of these two studies indicate that these two sensors, the ERTS-1 operating in the visible and near-visible portion of the electromagnetic spectrum, and the SLAR operating in the microwave portions, are indeed complementary. They have both been shown to provide a data set which is in part unique to the system, and which, in concert, increases the accuracy of the data interpretation.

The fact that the data used may both be obtained from satellite altitudes increases the validity of the philosophy behind this work. One of the major problems with respect to the near real-time application of remote sensing data is the need for a timely distribution of the data. The ground-truth and interpretation schemes used in this work demonstrate that such data can easily and accurately be used by individuals and small organizations for use on the local level. The interpretation techniques used are based primarily on the standard photo interpretation approach, coupled with the proper type of ground truth.

PREFACE

This work was prepared with the valuable assistance of a number of persons from the Environmental Research Institute of Michigan and the Geography Department of The University of Michigan. Mr. Richard Larson discussed the electrical measurements of snow and ice, designed the field instruments used in these studies, and contributed valuable assistance in the field. He also wrote sections 3.2.2 and 3.2.3. Dr. M. G. Marcus (formerly Geography Department, University of Michigan; now Geography Department, Arizona State University, Tempe, Arizona) together with B. Haack and W. Benjey helped conduct the field program during the winter ice and snow studies at Douglas Lake, Michigan.

For the portion dealing with the shoreline flooding of Monroe County, Michigan, the author was assisted primarily by three individuals. Ms. Linda Wilock conducted the work involving the ERTS-1 Computer Compatible Tapes, C. Davis interpreted the ERTS-1 Band 7 imagery (Figure 23), and R. Shuchman prepared one of the SLAR interpretation maps (Figure 22b). In addition, these latter two individuals collected data and conducted interviews about the floods during the April 1973 storms.

The entire project was sponsored by the National Aeronautics and Space Administration, Goddard Space Flight Center (Contract NAS5-21783). Mr. E. Sjzana was the project manager, and Dr. F. Quinn (National Oceanic and Atmospheric Agency, Detroit, Michigan) the technical monitor.

Drs. P. Jackson and L. J. Porcello (ERIM) provided suggestions and guidance for the duration of the project. However, all responsibility for the accuracy, interpretations and final conclusions contained in this report rest with the author.

CONTENTS

ABBREVIATIONS	9
SYMBOLS	10
1. SUMMARY	11
2. INTRODUCTION	14
3. STUDIES OF ICE AND SNOW	23
3.1 Interpretation of ERTS-1 Imagery	23
3.1.1 Radiometric Ground Truth	23
3.1.2 Data	24
3.1.3 Analysis of Data	24
3.1.4 Discussion	32
3.1.5 Conclusions to ERTS-1 Studies	39
3.2 Interpretation of SLAR Data of Great Lakes Ice and Snow	39
3.2.1 Review of Work with SLAR	41
3.2.2 The Radar System	43
3.2.3 The Experiment	44
3.2.4 Conclusions to SLAR Studies	53
3.3 Conclusions to Ice and Snow Studies	55
4. STUDY OF MONROE COUNTY, MICHIGAN FLOODING, APRIL 1973	57
4.1 Presentation and Interpretation of Data	63
4.2 Photo Interpretation of Remote-Sensing Imagery	65
4.3 Study of ERTS-1 Computer Compatible Tapes	77
4.4 Conclusions to Flooding Studies	86
5. CONCLUSIONS AND RECOMMENDATIONS	87
APPENDIX	91
REFERENCES	98
REPORTS AND PAPERS PREPARED UNDER THIS CONTRACT	102
DISTRIBUTION LIST	104

PRECEDING PAGE BLANK NOT FILMED

FIGURES

1. Index Map of Study Areas	15
2. Classification of Lake Ice	21
3. Spectral Response from Ice and Snow Surfaces	25
4. ERTS-1 Imagery, Whitefish Bay, Michigan, 29 March 1973.	26
5. ERTS-1 Imagery, Green Bay, Wisconsin, 5 February 1973	27
6. Interpretation of ERTS-1 Imagery for Whitefish Bay, Michigan, 29 March 1973	29
7. Ice on Whitefish Bay, Michigan, 28 March 1973	30
8. Interpretation of ERTS-1 Imagery for Green Bay, Wisconsin, 5 February 1973	33
9. Ice on Green Bay, Wisconsin, 5 February 1973	34
10. Radar Image of Lake Superior Ice	42
11. Portable Q-Meter for Measuring Dielectric Constant and Loss Tangent	46
12. Profile of Temperature, Density and Dielectric Constant of Snow Bank, Douglas Lake, Michigan, 22 February 1973	49
13. Contour Plot of Relative Dielectric Constant Values, Douglas Lake, Michigan, 22 February 1973	50
14. Diagram of Instrumentation Used to Measure Electrical Properties at Wavelengths of 3 cm and 20 cm	51
15. Instrumentation Used to Measure Electrical Properties at Wavelengths of 3 cm and 20 cm	52
16. Sidelooking, Imaging Radar Geometry for Two Imaging Passes	54
17. Index Map for Monroe County, Michigan	59
18. Wind Set-up and Seiche on Lake Erie, 12-16 November 1972	61
19. Lake Erie Water Levels, Stony Point, Michigan (Station 3090), March-May 1973	62
20. Interpretation of Aerial (IR) Photographs, Monroe County, Michigan, 11 April 1973	66
21. Interpretation of SLAR Imagery, Monroe County, Michigan, 5 April 1973	68
22. Interpretation of ERTS-1 Band 7 Imagery, Monroe County, Michigan, April 1973	69
23. Interpretation Maps of Coastal Areas, Monroe County, Michigan, April 1973	74
24. Digital Print-out of Level Slicings, Data Divided into Eight Linear Gray Levels	79

25. Digital Print-out of Level Slicings, Data Divided into Ten Histogram Gray Levels	80
26. Digital Print-out of Level Slicings, Using the "Percentage Area" Method	82
A-1. IR Photography, Monroe County, Michigan, 11 April 1973	92
A-2. IR Photography, Monroe County, Michigan, 11 April 1973	93
A-3. IR Photography, Monroe County, Michigan, 11 April 1973	94
A-4. IR Photography, Monroe County, Michigan, 11 April 1973	95
A-5. ERTS-1 Imagery, Monroe County, Michigan, 14 April 1973	96
A-6. SLAR Imagery, Monroe County, Michigan, 5 April 1973	97

TABLES

1. Department of Great Lakes Temperatures from Normal	16
2. Opening of Navigation Seasons	17
3. ERTS-1 Data Available for Whitefish Bay Study Area, Winter Season, 1972-1973	18
4. Measured Spectral Radiance from Surfaces with Moderate Uniform Snow Cover	36
5. Wavelength Response Characteristics of the 12-Channel Spectrometer	37
6. Examples of Measured Values of $\tan \delta$, λ and ϵ_i for Snow	48
7. Data Collection of Lake Erie Shoreline Study, Monroe County, Michigan, April 1973	58
8. Interpretation Scales of Imagery Used in the Monroe County Flooding Study	64
9. Comparison of ERTS-1 and SLAR Imagery Interpretation to B&W IR Photographic Data	71
10. Percentage of Area in Each Ground Surface Category for Three Coastal Study Sites	76
11. Aerial Comparison of Three Coastal Study Areas, Using Density Slicings from ERTS-1 (CCT-MSS7)	78
12. Data Ranges from ERTS-1 (CCT-MSS7) for Open Water, for Three Coastal Areas	83

ABBREVIATIONS

AD	Analog to Digital
B&W IR	Black and White Infrared Photographs
CCT	Computer Compatible Tapes
CK	Creek
cm	Centimeter
ERTS-1	Earth Resources Technology Satellite - 1
FOV	Field of View
ft	Feet
GHz	Gigahertz
HH	Horizontal Transmit - Horizontal Receive (Radar Polarization)
HV	Horizontal Transmit - Vertical Receive (Radar Polarization)
in	Inch
km	Kilometer
m	Meter
MHz	Megahertz
mi	Mile
MSC	Manned Spacecraft Center
NASA	National Aeronautics and Space Administration
RPMI	Radiant Power Measuring Instrument
SIPRE	Snow Ice and Permafrost Research Establishment (Now CRREL - Cold Regions Research Engineering Laboratory)
SLAR	Side-Looking Airborne Radar
VSWR	Variable Standing Wave Ratio
VV	Vertical Transmit - Vertical Receive (Radar Polarization)

PRECEDING PAGE BLANK NOT FILMED

SYMBOLS

G_a	Antenna Gain
S_L	Backscattered Energy Value at (Radar) L-band
S_X	Backscattered Energy Value at (Radar) X-band
Q	Cross-Polarization Ratio
Q_L	Cross-Polarization Ratio at (Radar) L-band
Q_X	Cross-Polarization Ratio at (Radar) X-band
$^{\circ}$	Degrees
$^{\circ}C$	Degrees Centigrade
$^{\circ}F$	Degrees Farenheit
ϵ_1, ϵ	Dielectric constant
σ	Echoing (scattering) cross-section
$'$	Feet
E	Field strength
θ_1	Incident Angle
O	Incoming Radiation
η	Index of Refraction
$\tan \delta$	Loss Tangent
μm	Micrometer
G	Outgoing Radiation
P_s	Received Power
P_t	Transmitted Power
R	Range
λ	Wavelength

A COMPARISON OF ERTS-1 AND SLAR DATA FOR THE STUDY OF WATER RESOURCES

1

SUMMARY

This final report concerns the work conducted under Task IV of NASA Contract NAS5-21783 between 1 July 1972 and 30 August 1974. The project was originally designed as a comparison of imagery collected using a dual-frequency, dual-polarized Side Looking Airborne Radar (SLAR) and that obtained by the Earth Resources Technology Satellite (ERTS-1). For this comparison, snow and ice, specifically freshwater lake ice in the upper Great Lakes area, was to be the subject of the study. However, weather conditions coupled with delays in the preparation of the radar system dictated that the work would not be completed during the 1972-1973 winter season. Consequently, the orientation was changed to study water levels and lake shore flooding along the western shore of Lake Erie in Monroe County, Michigan. Data collected during this time included SLAR and ERTS-1 supplemented by black and white infrared (B&W IR) aerial photography.

This report is therefore divided into two major parts. The first describes the approaches and progress which have been made relative to the study of lake ice while the second discusses the work conducted and the conclusions reached with respect to the study of lake shore flooding. SLAR and ERTS-1 data are the primary inputs for each study, with B&W IR providing much of the "control" data for the Monroe County work.

One of the primary objectives of the work, in addition to comparing several remote sensing data collection systems, was to attempt to determine the degree to which information could be extracted from the data using traditional photo interpretation methods. Although numerous sophisticated methods are available for the analysis of remotely-sensed data, it is the philosophy of the author, and the objective of this work, that until these data are utilized through fairly straightforward techniques there will be little call for them by individuals and/or small government organizations. These users are often the ones in greatest need of such data, for they commonly can neither launch large data collection efforts or fund extensive analysis programs. Our analysis was conducted primarily in the realm of aerial photographic interpretation techniques, using data easily available and employing procedures which are possible in the average darkroom. It is the hope that we have demonstrated the utility of these data as an information source for small governmental units (e.g., counties, townships, etc.) and also the utility of these data for real-time operations (e.g., shipboard operations in ice-covered waters). By bypassing extensive and expensive machine technology, which although often yielding a more precise analysis, also often requires considerable time for the preparation of the data, we endeavor to bring remote sensing closer to the needs of the immediate data users.

This work draws the following conclusions:

1. For the visual analysis of ERTS-1 imagery, a basic set of radiometric signatures are easily and cheaply obtainable by the researcher working in his own field area. Such data may be collected at the time of the satellite pass, requires a minimum of manipulation and quickly provides necessary guidance for visual interpretation of the ERTS-1 imagery.
2. For studies of lake ice, ERTS-1 Band 7 has proven to be the best suited for identifying open water and open-pack ice. As the amount of open water in the scene decreases, or as the amount of free water in the snow decreases, there is a decided advantage in using shorter wavelengths for scene identification. However, in cases where the spectral response curve is essentially flat for all wavelengths (e.g., snow), all four ERTS-1 bands are necessary for adequate identification.
3. The study of the electrical properties of the ice and snow pack is fruitful in that the low dielectric constant (ϵ_i) and low loss tangent ($\tan \delta$) indicate that energy penetration can be considerable in the cases of the ice and snow having no free water. This expands the information available beyond that obtained by ERTS-1, and comparison of the two data sets should yield a considerable amount of additional information about the subject material.
4. SLAR apparently gives information concerning the internal structure of the snow and ice, as opposed to the surface information which is available from ERTS-1, and consequently supplements the ERTS-1 data.
5. For the monitoring of ice, all four ERTS-1 bands are useful and generally necessary. There is some argument for the finer division of the ERTS-1 bands (i.e., finer spectral resolution), especially in the longer wavelengths where the spectral response curve rapidly decreases with increasing wavelength. No conclusion may be drawn concerning the SLAR imagery for ice because there were no data available at the time this study was being conducted.
6. The measurement of floods and flooding areas (using ERTS-1 Band 7 only) is quite promising. Identification of the small land and water areas which tend to be obscured within the resolution element of the system is a problem.
7. Band 7 of ERTS-1 did not allow the detection of the several small towns in the Monroe County, Michigan study site. Alternatively, those urban sites which were flooded were easily identified as flooded. The SLAR detected the same built-up areas, but it was not always possible to identify them as flooded on this imagery. By combining the two systems, the identification of the flooded towns is easily and accurately achieved using the photo-interpretation approach. The near simultaneous and near real-time availability of data from the two sensors could be extremely useful for guidance of flooding and post-flooding rescue and disaster relief operations.

8. Because the resolution cell of ERTS-1 is relatively large (approximately 300 ft), it appears rational and necessary to supplement this system with a fine resolution active microwave imaging system such as SLAR. This would allow the continual monitoring of some sites through most weather conditions, and the collection of data over a wide portion of the electromagnetic spectrum during periods of high atmospheric attenuation in the visible portion of the spectrum.
9. In the case of floods, it appears that the ERTS-1 Band 7 is the single best band for monitoring both water and moist and saturated soils. For these studies, SLAR X-Band (HH, HV) gave most of the radar information resulting from the image interpretation.
10. It is also concluded that the near real-time availability of these data should be strongly encouraged, although the data need not be confined to the same level of (technology) sophistication. For the examples used herein, near real-time (less than 12 hours) data dissemination is mandatory if a goal is the inclusion of numerous smaller organizations in the utilization of the data for guidance coping with on-going meteorological events.
11. It is a relatively easy task to use the ERTS-1 CCT for identifying the location of a given ground surface if the following two items are known: a) the location of the radiometric response of that surface in the continuum of the gray scale for the study scene and b) the percentage of the study area which is covered with that particular ground surface.
12. The combination of the SLAR and ERTS-1 data are definitely complementary to one another, as demonstrated in the case of the built-up and flooded areas. SLAR was instrumental in identifying these areas as built-up, whereas ERTS-1 Band 7 were necessary to identify the flooded condition.

2

INTRODUCTION

Although the 1972-1973 ice season confirmed the predictions for an early freeze-up in some of the more isolated portions of the upper Great Lakes, the warmer-than-normal thaw in late January rapidly stabilized or diminished the ice development in the northern areas, including the study site of Whitefish Bay (Fig. 1). It wasn't until 8 February 1973 that the last ship cleared the locks at Sault Ste. Marie, a date which was one week later than the record set in the previous year. The winter remained unseasonably warm in all lakes, with March, 1973 exhibiting a $+5.1^{\circ}$ to $+5.7^{\circ}\text{C}$ ($+9.0$ to $+10.0^{\circ}\text{F}$) departure from the norm (Table 1). The opening of the 1973 navigation season was not only one of the easiest, but also one of the earliest on record (28 March 1973, the first time in 20 years of an opening prior to 1 April), occurring about two weeks before the average opening date (Boyce, 1973) (Table 2). By this time, Sault Ste. Marie was several hundred degree days above the historical norm.

The short ice season was to the distinct advantage of the shipping interests, but it led to a series of problems for the project. The lack of ice of sufficient thickness and cover precluded the proper field work which was to consist of reflectance, thickness, electrical and roughness measurements of the ice cover of Whitefish Bay. A second major problem was the considerable reduction in the time during which a good set of ice data could be obtained via satellite multi-spectral scanners, a fact which led to some major changes later in the project.

Table 3 presents the coverage of the ERTS-1 data which are available for the Whitefish Point study area for the 1972-1973 ice season. These data clearly illustrate the problems relative to the cloud cover in the study area. It is noted that ice was not present to any extent, at least not of sufficient coverage to restrict shipping, until early February, and then only until early April when the shipping season reopened. During that time there were only four ERTS-1 passes which would have shown ice. Of these, three had 90% or more cloud coverage, one had 60% cloud cover with thin clouds over the study area, and two (29 and 30 March 1973) showed some good ice data from the Whitefish Bay area.

The next major problem related to the preparedness of the SLAR system, which, due to several malfunctions, was not operative until 5 April 1973. This was approximately one week following the best set of ERTS-1 data (29 March 1973). By that time the ice in Whitefish Bay had disintegrated to a point which made it impossible to do the ground truth considered necessary for completion of the original task. Also, due to the rapid ablation of the ice and the problem of clouds obscuring the study area, a wait until the next satellite pass (on 16-17 April 1973) was not warranted. The decision was made to shift the major emphasis of the study from the ice in eastern Lake Superior to the shorelines of the western portion of Lake Erie. This decision,

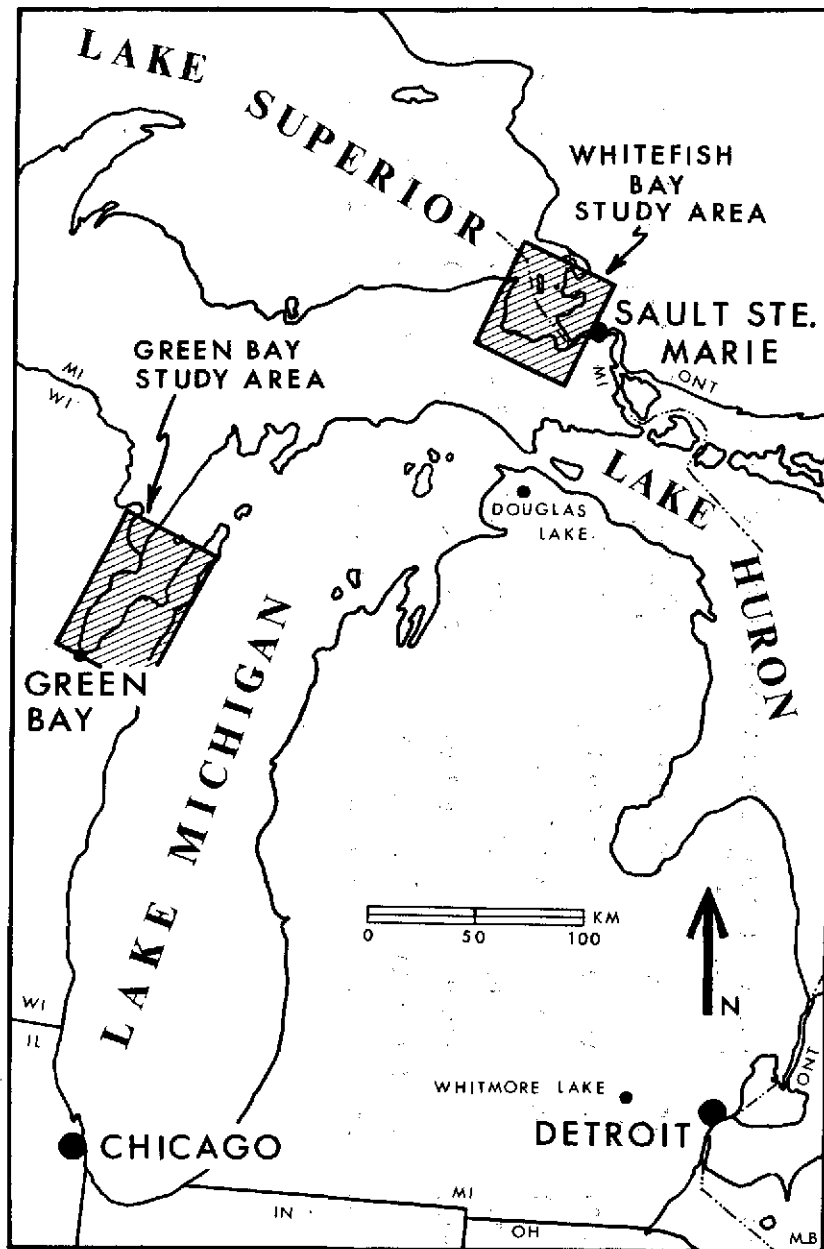


FIGURE 1. INDEX MAP OF STUDY AREAS

TABLE 1. DEPARTURE OF GREAT LAKES TEMPERATURES FROM NORMAL
(From: Boyce, 1973)

Month	Lake Superior		Lake Michigan		Lake Huron		Lake Erie		Lake Ontario	
	$^{\circ}\text{C}$	$(^{\circ}\text{F})$	$^{\circ}\text{C}$	$(^{\circ}\text{F})$	$^{\circ}\text{C}$	$(^{\circ}\text{F})$	$^{\circ}\text{C}$	$(^{\circ}\text{F})$	$^{\circ}\text{C}$	$(^{\circ}\text{F})$
November (1972)	-0.56	(-1.0)	0.06	(-0.1)	0.61	(-1.1)	1.11	(-2.0)	1.72	(-3.1)
December (1972)	5.83	(-4.8)	2.11	(-3.8)	0.11	(-0.2)	1.39	(+2.5)	2.39	(+4.3)
January (1973)	-1.67	(+3.0)	1.95	(+3.5)	1.56	(+2.8)	1.39	(+2.5)	1.89	(+3.4)
February (1973)	-0.50	(+0.9)	1.11	(+2.0)	0.89	(-1.6)	0.89	(-1.6)	1.50	(-2.7)
March (1973)	+5.61	(+10.1)	5.28	(+9.5)	5.11	(+9.2)	5.44	(+9.8)	5.67	(+10.2)
November (1972)	-0.89	(+1.6)	1.22	(+2.2)	1.00	(+1.8)	1.22	(+2.2)	1.33	(+2.4)

TABLE 2. OPENING OF NAVIGATION SEASONS
(From: Boyce, 1973)

<u>Location</u>	<u>Forecasted 1973 Opening- Icebreakers</u>	<u>Forecasted 1973 Opening- Natural</u>	<u>Actual 1973 Opening</u>	<u>Average Opening (Historical)</u>	<u>Earliest Opening</u>
Duluth	April 2	April 11	*March 29	April 10	March 1, 1911
Whitefish Bay	March 30	April 10	**March 28		
St. Mary's River	March 29	April 9	**March 28	April 14	March 22, 1942
Straits of Mackinac	March 24	April 7	*March 20	April 4	March 18, 1964
Green Bay	March 29	April 8	**March 31	April 12	March 24, 1946
Southern Lake Huron	March 18	March 26	*March 14		
Saginaw Bay	March 26	April 1	(ice-free on March 15)		
Detroit	March 18	March 26	*March 14	March 23	March 1, 1937
Western Lake Erie (Cleveland)	March 20	March 27	*March 20	March 24	March 1, 1937
Buffalo	April 4	April 14	*March 20	April 11	March 2, 1953

*Without direct icebreaker assistance

**Not known whether icebreaker assistance rendered

TABLE 3. ERTS-1 DATA AVAILABLE FOR WHITEFISH BAY STUDY AREA
1972-1973 Winter Season

EAST	23NOV72 1123-15580 90% (NI)	11DEC72 1141-15580 50% (I)*	29DEC72 1159-15575 100% (IP)	16JAN73 1177-15573 20% (1)*+	03FEB73 1195-15573 100% (IP)	21FEB73 1213-15581 90% (IP)	11MAR73 1231-15582 90% (IP)	29MAR73 1245-15583 20% (I) ^o	16APR73 1267-15582 100% (IP)
WEST	24NOV72 1124-16032 70% (NI)	12DEC72 NO DATA	30DEC72 1160-16030 100% (IP)	17JAN73 1178-16033 100% (IP)	04FEB73 1196-16032 100% (IP)	22FEB73 1214-16032 60% (1)'	12MAR73 1232-16034 70% (IP)	30MAR73 1250-16034 20% (I) ^o	17APR73 1268-16034 20% (1)''

NOTES:

I = Ice Visible
IP = Ice Probable
NI = No Ice Visible
NIP = No Ice Probable

* Ice on St. Marys River, Inland Lakes and Protected Bays

+ Thin clouds over study area, Ice on Canadian Portions (Goulias Bay, Batchawana Bay and west of Ile Parisienne)

^o Ice in Tahquamenon Bay, and areas between Whitefish Point and Ile Parisienne;
ice also in Goulias Bay and Batchawana Bay.

' Ice and thin clouds over entire study area

'' Small amounts of ice in small bays and along shore

done with the concurrence of the program monitor, permitted data collection operations which provided the data that will be the subject of the next chapter.

As indicated above, the optimal temporal combination of both ERTS-1 and SLAR data for studying fresh-water lake ice in Whitefish Bay, was not available. However, during the satellite passes of 4 February 1973, a ground truth team was in the field preparing for the proposed work. Originally, studies of the ice in both the Great Lakes and on several smaller inland lakes were planned. The objectives of this work were:

1. To determine the type and distribution of freshwater ice in the upper Great Lakes and to study the feasibility of determining ice thickness under a varying snow cover, using ERTS-1 and SLAR methods and imagery;
2. To study the distribution and measurable parameters of the snow pack and ice of the upper Great Lakes area for ground truthing the remotely-sensed data and;
3. To study and evaluate the importance of the two-sensor approach to the study of lake ice and snow pack; to determine what proportion of necessary and relevant information can be derived from each sensor package and what reliability data from a given sensor or set of sensors will have in terms of predicting ice and snow pack growth, movements, ablation and dissipation.

The rationale for the two-sensor approach, using one operating in the visible and near visible and the other in the microwave, follows.

Although aerial photography of lake ice, through both space and time, has been an important source of data for some years, the collection of these data has hitherto been dependent upon suitable flying weather. With respect to the ERTS-1 imagery weather can interfere in another way, for the development of clouds between the ground and the sensor will obscure the former from the latter. Such a condition does not affect SLAR (which is, essentially, an all-weather sensor), but as long as the SLAR is airborne the flying conditions for the aircraft will dictate the feasibility of this instrument for a viable data source. By pursuing the collection of the SLAR data, in conjunction with the ERTS-1 data, it was thought that some relatively important statements concerning the usefulness of these sensors for ice data, both in an independent and comparative sense, could be made.

In addition, we recognize that one sensor alone cannot provide all of the pertinent and necessary data for all possible users and uses. For example, the data collected in the visible (using, for example, photography) generally cannot provide direct information relative to the ice thickness or snow depth. By using multi-sensors these data may still not be available, but additional surrogates could be collected and compared to infer other more meaningful and pertinent data and information. This would allow the fulfillment of the second objective mentioned above and to make more meaningful statements concerning the contributions of different sensors

to ice and snow studies. Finally, there is the need for ground truth which is both comprehensive and continuous in remote sensing experimentation. Such data, reflecting the conditions of the earth's surface at the time they were collected are increasingly necessary because we are moving from a period of instrument design and development into one of application of the data collected by these instruments. In this particular study numerous parameters (some of which can be remotely sensed) have been identified with regards to the initiation, growth and dissipation of ice sheets. Most standard weather parameters (e.g., degree days, winds, cloud cover and the like) are already routinely taken by the weather services. However, there are few on-going studies of parameters such as isolation, moisture content of snow, snow density, ice thickness, water temperatures, snow depths and dielectric constant of surface materials. These factors are of utmost importance, for they are indicators of the nature of the surface materials; and as indicated earlier, as these parameters change through time, the remote sensor may detect this change. We thus need to have extensive ground truth which will document changes in the ice and snow covers through space and time, provide more accurate interpretations of the remotely sensed data and aid in the development of interpretation keys.

Hence, the approach is to relate ERTS-1 data, SLAR data and ground truth data concerning ice and snow to one another thus affording a more realistic realization of objective (3) noted above.

In addition it is noted (Figure 2) that there are considerable variations in the types of freshwater ice which develop (Wilson, et al., 1954). Some, such as slush, are of little hazard to navigation although they often impede a ship's progress, whereas sheet ice and floes are navigational hazards, depending upon their thickness, size, movement, pressures and the like. These variations, though briefly noted, must be documented to avoid misinterpretation of the imagery.

The ground-truth team was in the field during February and March 1973. During this time some baseline data were acquired over the ice and snow surfaces in preparation for the remotely sensed data collection. This team was stationed at The University of Michigan Biological Field Station at Douglas Lake, Michigan (Fig. 1), which allowed them access to both the inland lake ice of Douglas Lake and to Pelston, Michigan (Emmett County) airport.

This winter's work was designed to determine both the design and development of instruments for the measurement of electrical ground truth parameters. The work consisted primarily of two sets of measurements:

- a) Radiometric measurements - for determination of spectral signatures of different snow and ice types, for ERTS-1 data interpretation.
- b) Dielectric measurements - for determination of dielectric measurements of snow packs and freshwater lake ice, for SLAR imagery interpretation.

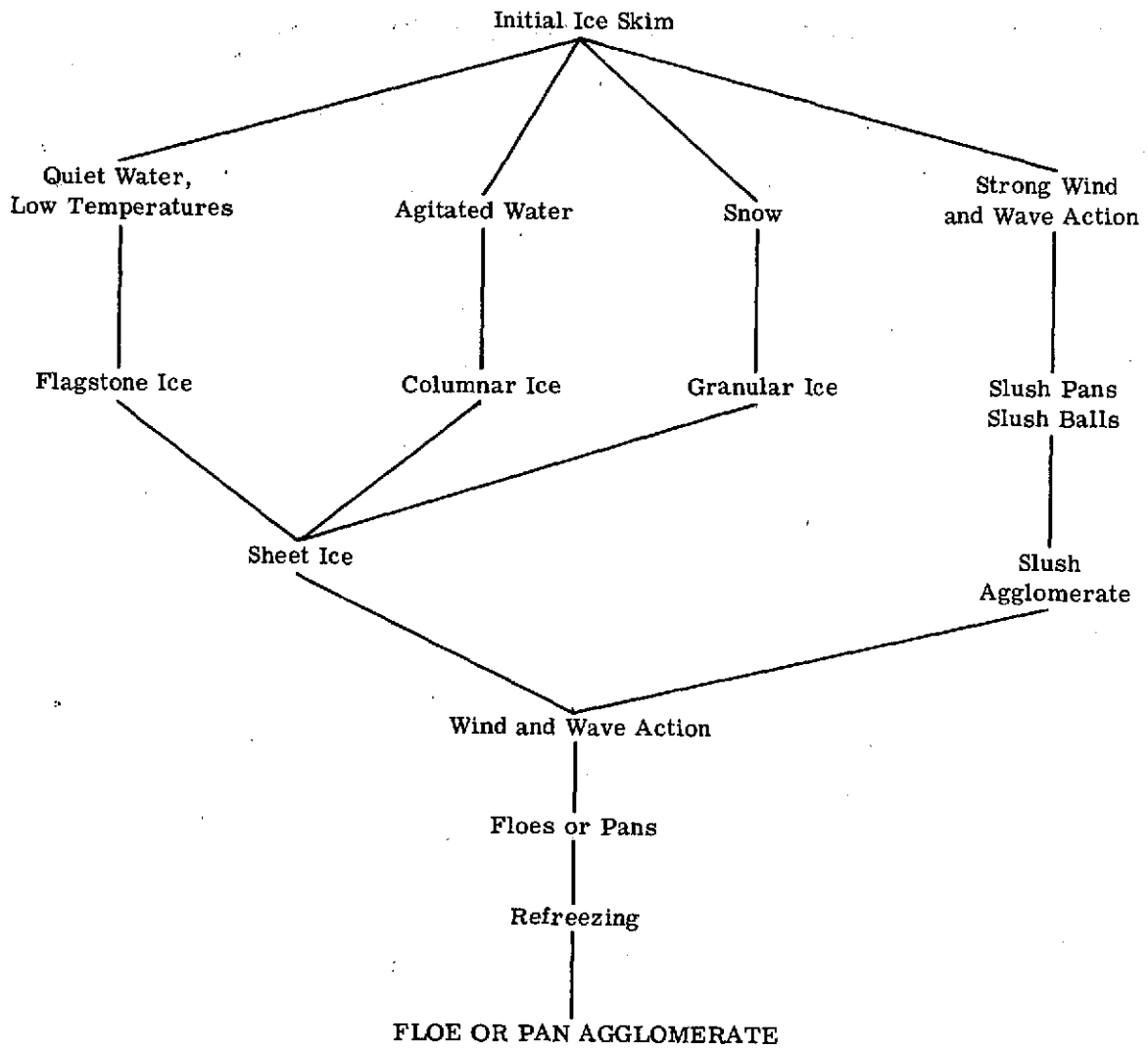


FIGURE 2. CLASSIFICATION OF LAKE ICE. (After Wilson, et al., 1954.)

Two different sets of field data were collected at this site, and at several other sites during the 1972-1973 winter. The results of these preliminary studies were previously presented as part of the ERTS-1 progress report (Thomson, et al., 1973(d), Bryan, 1973(b), and Bryan and Larson 1973). These are summarized in the following two Sections of this report.

STUDIES OF ICE AND SNOW

3.1 INTERPRETATION OF ERTS-1 IMAGERY

3.1.1 RADIOMETRIC GROUND TRUTH

Many radiometric data have been collected over ice and snow surfaces for various types of studies, including remote sensing ground truth (e.g., Horvath and Brown, 1971). It is necessary that a proper ground truth operation be conducted in support of remote sensing and that the field data be collected for the same bands of the electromagnetic spectrum as those in which a sensor operates. To aid in the collection of the necessary radiometric ground-truth data in conjunction with the ERTS-1 satellite, three instruments are available: (a) The Bendix Radiant Power Measuring Instrument (RPMI); (b) the EXOTECH Model 100; and (c) the Gamma Scientific Monitor*. These instruments can be used for obtaining incident radiation using a 180° hemispherical field of view (FOV) and for measuring scene reflectance. For the latter measurements, the RPMI has a solid angle FOV of 6° whereas the EXOTECH has a FOV of 15° .

The radiometric response is an integration of the spectral measurement over the entire scene viewed, or in the case of the satellite, for the data (resolution) cell. Some problems can thus arise, especially where a very detailed reading of the ground may represent only a small portion of the ERTS-1 resolution cell. Consequently, by measuring large areas and obtaining numerous measurements over similar surfaces, it is hoped that the ground truth reading may be adequately related to the ERTS-1 images for purposes of interpretation.

Another major problem for ERTS-1 image interpretation, given the existence of the target reflection data, is the calculation of the atmospheric attenuation scattering of the energy between the ground and the satellite sensors. Rogers and Peacock (1973) have worked on this problem and present the theory for calculating atmospheric parameters (beam transmittance, path radiance), determining target reflectance and then employing these parameters for translating the ERTS-1 data into the corrected target reflectance characteristics. Our concern, in the present paper, is to present several modified target reflectance curves (in the ERTS-1 spectral bands) for snow and freshwater ice features which, upon application of the proper correction techniques, may allow accurate machine and human interpretation of the ERTS-1 data.

* (a) Bendix Aerospace Systems Division, 3300 Plymouth Road, Ann Arbor, Mich. 48107
 (b) EXOTECH, Inc. 1200 Quince Orchard Blvd., Gaithersburg, Md. 20760
 (c) Gamma Scientific, Inc., 3777 Ruffin Road, San Diego, Calif. 92123

(Identification of equipment by manufacturers or trade mark in no way implies an endorsement of such equipment. Such identifications are for explanatory, descriptive or scientific communication purposes only.)

This type of radiometric ground-truth is important for snow and ice studies because:

- a) The shape, size and location of the subject is, especially in the case of pack ice, constantly changing and consequently cannot always be accurately applied to interpretation over a time series of satellite images; and
- b) Especially in the spring and fall, in higher latitudes and throughout the winter in mid-latitudes, the temperature of the surface material fluctuates around the freezing point. Consequently, the surface is alternating from wet to dry, the rate of this fluctuation being dependent on weather and meteorological conditions prevailing at the time.

3.1.2 DATA

Radiometric data for six types of ice and snow surfaces were collected during the 1972-1973 winter season at two sites (Douglas Lake, Emmett County and Whitmore Lake, Washtenaw County) in Michigan (Fig. 1). The six surfaces studied were: a) drained and refrozen slush; b) new snow; c) dry white ice; d) slush and water mixture; e) close pack (ice concentration 0.7-0.9); and f) open pack (concentration 0.4-0.6). For each site, four readings were taken; global irradiance; sky irradiance; direct beam irradiance and reflected radiance. Only the first and last of these are considered in this paper. All data were collected between 1000 and 1400 local sun time on days when the sky was clear and essentially cloud free. No data were taken when clouds obscured direct sun radiation to the observation site. All data were collected using the Bendix RPMI instrument which is thoroughly described by Rogers and Peacock (1973).

Figure 3 illustrates the variations in albedo for these six surfaces. These data were collected using the Bendix 6° FOV, with the instrument placed 1 m above and oriented normal to the surface. Essentially, then, this figure is a statement of the albedo in the four ERTS-1 bands for these surfaces. For each surface type, eight to ten sets of readings were made. Both the average and one standard deviation of the readings are plotted (Fig. 3) for each surface and for each ERTS-1 band.

ERTS-1 data in the form of imagery (Figures 4 and 5) are included as examples of the application of the radiometric ground truth data of the type presented in Figure 3. The two study sites are Whitefish Bay, Michigan (29 March 1973, ERTS-1 identification number 1249-15582) and Green Bay, Wisconsin (5 February 1973, ERTS-1 identification number 1197-1695). Locations for these two sites are indicated in Figure 1.

3.1.3 ANALYSIS OF DATA

3.1.3.1 Whitefish Bay, Michigan

If we assume that the six classifications of ice in Figure 3 adequately cover the types to be expected in the ERTS-1 imagery and that all ice in the ERTS-1 scenes are liable for classification

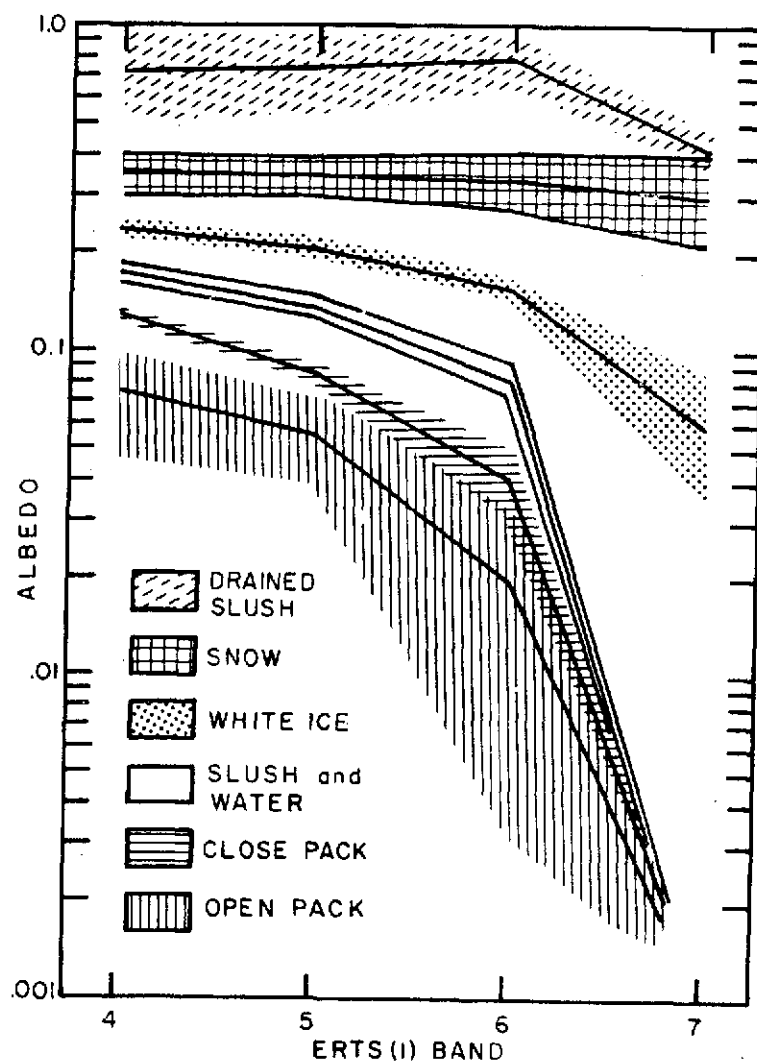


FIGURE 3. SPECTRAL RESPONSE FROM ICE AND SNOW SURFACES



FIGURE 4. ERTS-1 IMAGERY, WHITEFISH BAY, MICHIGAN, 29 Mar 1973.
Scene 1249-15582. Top: UL Band 4; UR Band 5.
Bottom: LL Band 6, LR Band 7.

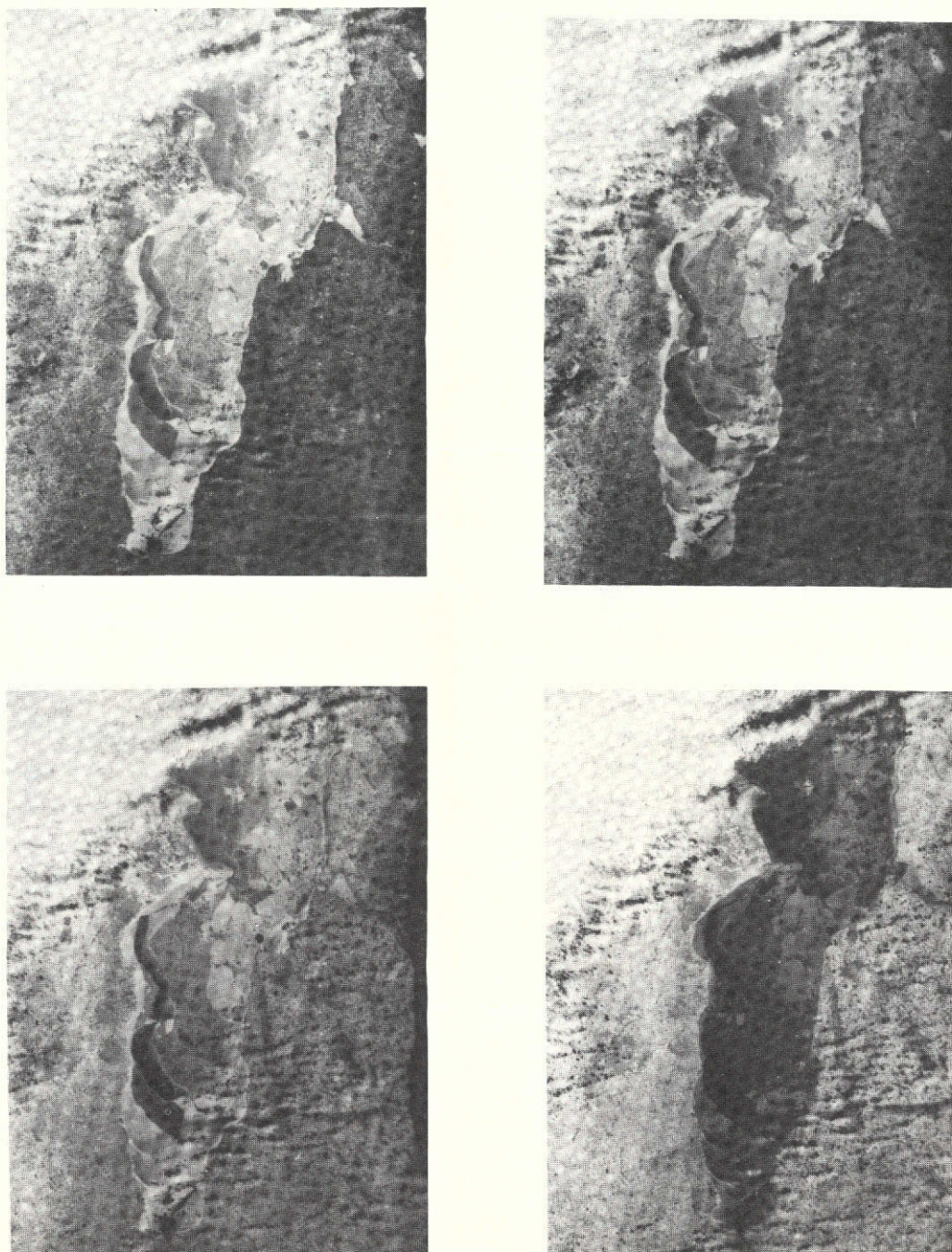


FIGURE 5. ERTS-1 IMAGERY, GREEN BAY, WIS.,
5 Feb 1973. Scene 1197-16095. Top: Band 4; Band 5.
Bottom: Band 6; Band 7.

into one of these six types, we can then, based partially upon the radiometric data, prepare an identification map of the lake ice.

Whitefish Bay, on the Michigan/Ontario border (Figures 4, 6, 7), has several features which are immediately apparent. Other than the jet contrail, trending SE-NW across the center of the bay, atmospheric interference with the ERTS-1 scene is of apparently minimal importance for the qualitative study. Shorelines and islands are easily distinguished, as are the Pleistocene beaches on Whitefish Point.

(A) Open Water: the areas of open water are identified as those having, in all four images, very low reflectance, and, from the Band 7 image, essentially no reflectance at all. Although not included in Figure 3, to use only Band 7 for open water recognition would be to possibly include both types of pack ice and also the slush/water classification. On Band 7 open water could not be confused with white ice, snow or drained slush (Fig. 3). Likewise, leads and other large openings in the ice are clearly identified using the same bands as for open water.

(B) Drained Slush: some ice in Tahquamenon Bay is best classified as "drained slush." We note from Figure 3 that there is a slight rise in the reflectance between Bands 4 and 6 and then a relatively large drop in Band 7. This type of surface is slush which has apparently refrozen slowly during a period when the free water has been draining out; it is highly porous, has a relatively low density and has a texture similar to that of a frozen sponge. Consequently, it has a rough surface (at least at these wavelengths) and because of its porous nature, scatters a great amount of light incident upon it. This ice therefore implies a given height above the water level, or, given a lower elevation, a relatively calm lake during periods of the draining. It also implies the existence of meteorological conditions very close to the freezing point, sufficient to allow draining prior to refreezing, but not to allow extensive melting of the entire ice parcel.

(C) Snow: snow has a lower albedo but, contrary to the other surfaces studied, this albedo is approximately constant in all four ERTS-1 bands. Several areas of snow are seen on the ice cover in Whitefish Bay study areas. These areas, if properly identified, indicate ice which has a slight snow cover of some indeterminable thickness and having essentially no free water. It is thus reasonable to state that the ice underlying the snow is solid, free of cracks and fissures, and also that the weather has been sufficiently cold to prevent melting of the snow. This surface may also have been the result of a recent snow fall.

(D) White Ice: white ice with a dry surface apparently covers a very large portion of the entire imaged area. Figure 3 indicates that although there is a drop in the albedo (with increasing wavelength), for this ice type this drop is small and the albedo in Band 7 is still quite sufficient to be detected by the ERTS-1 system. Consequently, the white ice should be easily differentiated from the surface types previously mentioned because of the lower reflectance

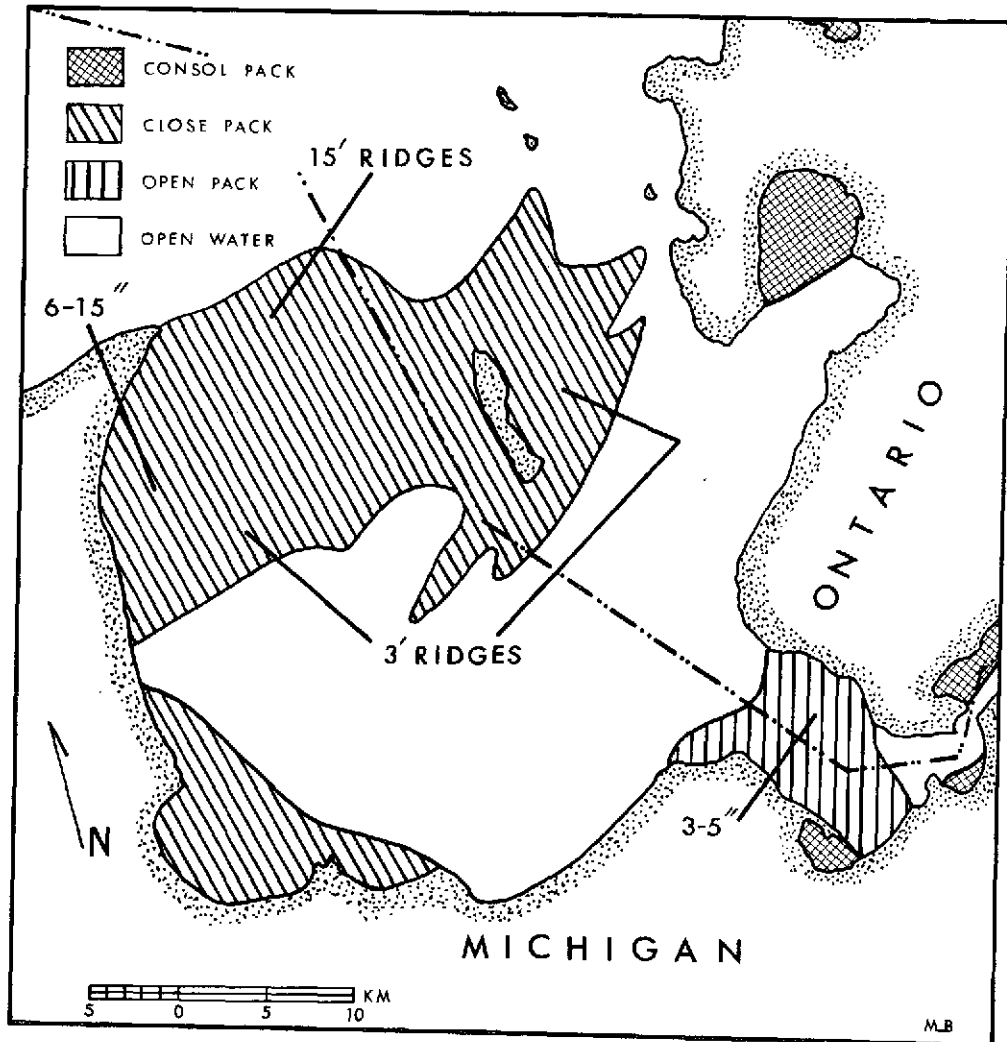


FIGURE 6. ICE ON WHITEFISH BAY, MICHIGAN, 28 Mar 1973.
(Source: U.S. Lake Survey, Detroit, Michigan)

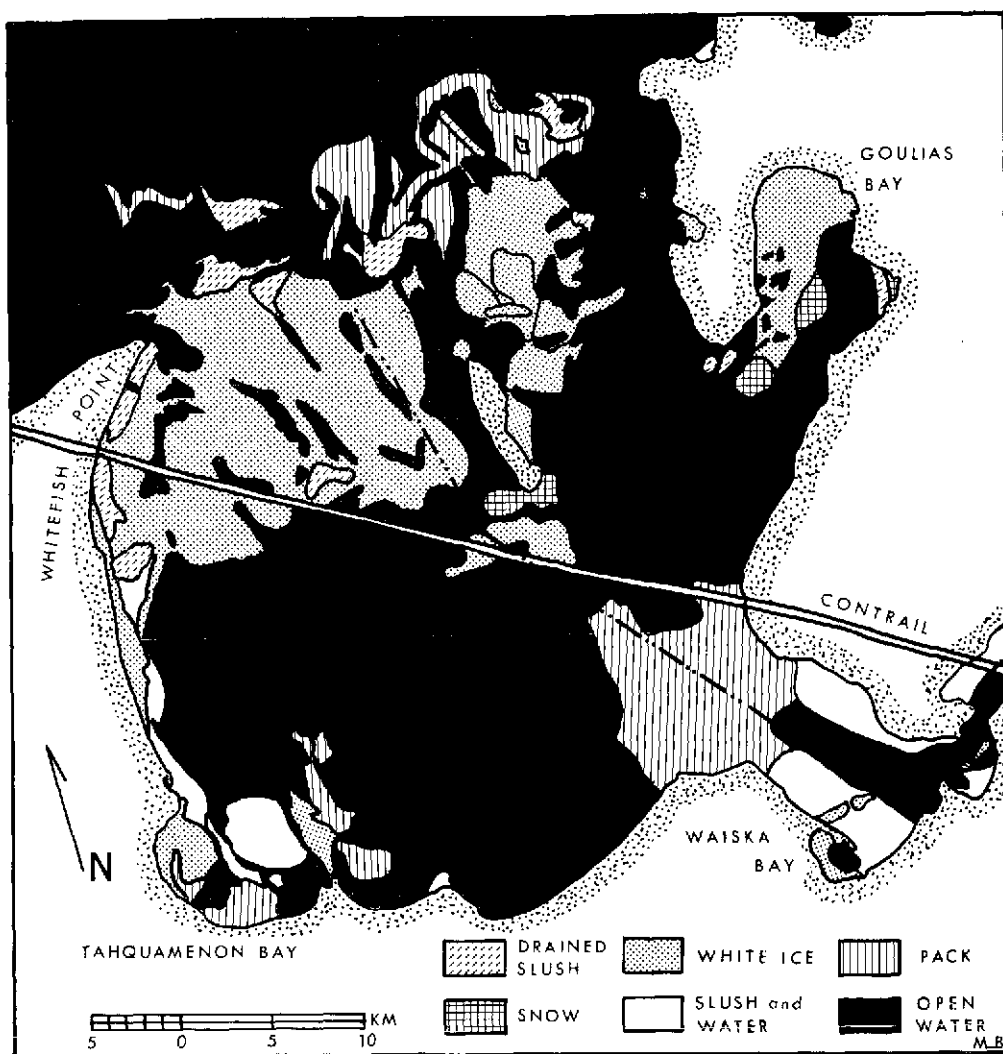


FIGURE 7. INTERPRETATION OF ERTS-1 IMAGERY FOR WHITEFISH BAY, MICHIGAN, 29 Mar 1973. Scene 1249-15582

curves and from those of lower albedo (Fig. 3) due to the higher reflectance in the 0.8-1.1 μm band (Band 7). White ice is essentially frozen slush and is, in several respects, a variation of the "drained slush" discussed above. In the white ice case, however, the water has been trapped and has been refrozen in place so that the density is much higher (approximately 0.75 to 0.90) and the porosity is reduced considerably. This ice type does not generally imply any given thickness and is one which, from the navigational point of view, probably should be avoided.

(E) Slush and Water/Light and Heavy Pack: these three types have the common feature of being very poor reflectors in the ERTS-1 Band 7. Albedo at the short wavelengths (Band 4) portion of the spectrum also decreases relative to the other ice types as the amount of water visible to the sensors increases. The albedo is decreased and generally, in addition to this decrease, there is an increase in the standard deviation. This is especially prominent in the case of the light pack. Some reflectance will be possible for all surfaces studied depending upon the amount of open water. The total area of ice needed for reflectance has not been determined and would, in any case, be partially a function of the sensitivity of the sensor employed.

In Whitefish Bay, several areas having these three ice types are identified. The general vicinity of Waiska Bay is classed as being predominantly slush and water. This decision is based upon reflectance but is also contingent upon the smooth and unbroken texture seen from this ice. One small area (probably dry white ice) extends across the center of this patch in a southwest-northeast direction.

Finally, areas of pack ice are seen to the north and northwest of the bay. In these areas the albedo decreases with increasing wavelength and thus pack ice is nearly imperceptible on the Band 7 image. No attempt is made to distinguish the heavy and light packs from one another.

No simultaneous ground truth data are available for the ERTS-1 scene, but the ice reconnaissance data for the previous day have been located. These data (Fig. 6) are based on visual aircraft reconnaissance.

The two data sets are not really comparable because they are dealing with two different classifications of ice. They also deal with two different time periods. However, we note that the main body of ice in Whitefish Bay is classed as rafted (to heights of 3-15 feet) in areas having coverage of 0.4-0.9 ice. The more protected bays (Tahquamenon and Goulais) are, based on these visual observations, free of ridged ice. These visual data also suggest that transportation through the main body of ice in Whitefish Bay would be quite difficult. However, given the lateness of the season and the amount of open water, ship passage should be safe within several days to several weeks (i.e., the first part of April) during this particular year. In fact, the first ship, SS John Munson, did clear the locks at Sault Ste. Marie just east of the study area on 28 March 1973, the day before these data were collected (Table 2).

3.1.3 2 Green Bay, Wisconsin

A second area of interest is Green Bay, Wisconsin (see Fig. 1). The data (Fig. 5) were collected approximately six weeks earlier (5 February 1973). Consequently, the ice coverage is more continuous and, in general, the areas of different spectral reflectances are more distinct and sharply identified.

Figure 8 is the interpretation of ERTS-1 imagery and Figure 9 presents the visual aircraft observations of ice for Green Bay. The albedo from Band 7 strongly suggests that a very large portion of the study area is covered with open water, but the high reflectance of some of the same areas in the other three bands indicates that many of these areas are not open ice-free water but have underlying ice features. The rationale for the interpretation of Figure 5 is as described for the Whitefish Bay, Michigan case and based partially on the curves presented in Figure 3.

3.1.4 DISCUSSION

The extraction of ice information from aerial photography is a well developed and useful aspect of air photo interpretation and photogrammetry (e.g., Marshall, 1966). As with other subjects of photo interpretation, the addition of imagery obtained with multiband cameras and the further sophistication of the spectral concept to the multispectral scanners (as used on ERTS-1) has added a new dimension to the science and also, in many respects to the level of information and detail which can be extracted. Numerous machine techniques are available for interpretation and for presentation of the data in a visual format. These are generally based upon the spectral recognition of various surfaces which are to be studied. Spectral responses, in the very straightforward manner and as used herein, are one method of approaching the subject. A more sophisticated approach requires computer hardware with a large storage capability and the decision-making software to compare the responses for each data cell in the study area and then to compare various combinations of the spectral responses for each band and for each data cell. A discussion of these methods is quite beyond the purposes of this report.

Of relevance, however, is the fact that ice data from fresh-water areas are available via the ERTS-1 satellite. More importantly, it appears as if useful information can easily be extracted from these data. The necessary basic inputs, the spectral reflectance curves, for both generic and genetic ice types are necessary if the type of work being discussed is to become operational. Development of spectral curves and a complete spectral library of ice types, possibly collected with both ground and aircraft based sensors, and for the same spectral bands as used on the ERTS-1 satellite should be the next logical step for the progression of this type of work. Then machine processing could be conducted with accuracy and validity.

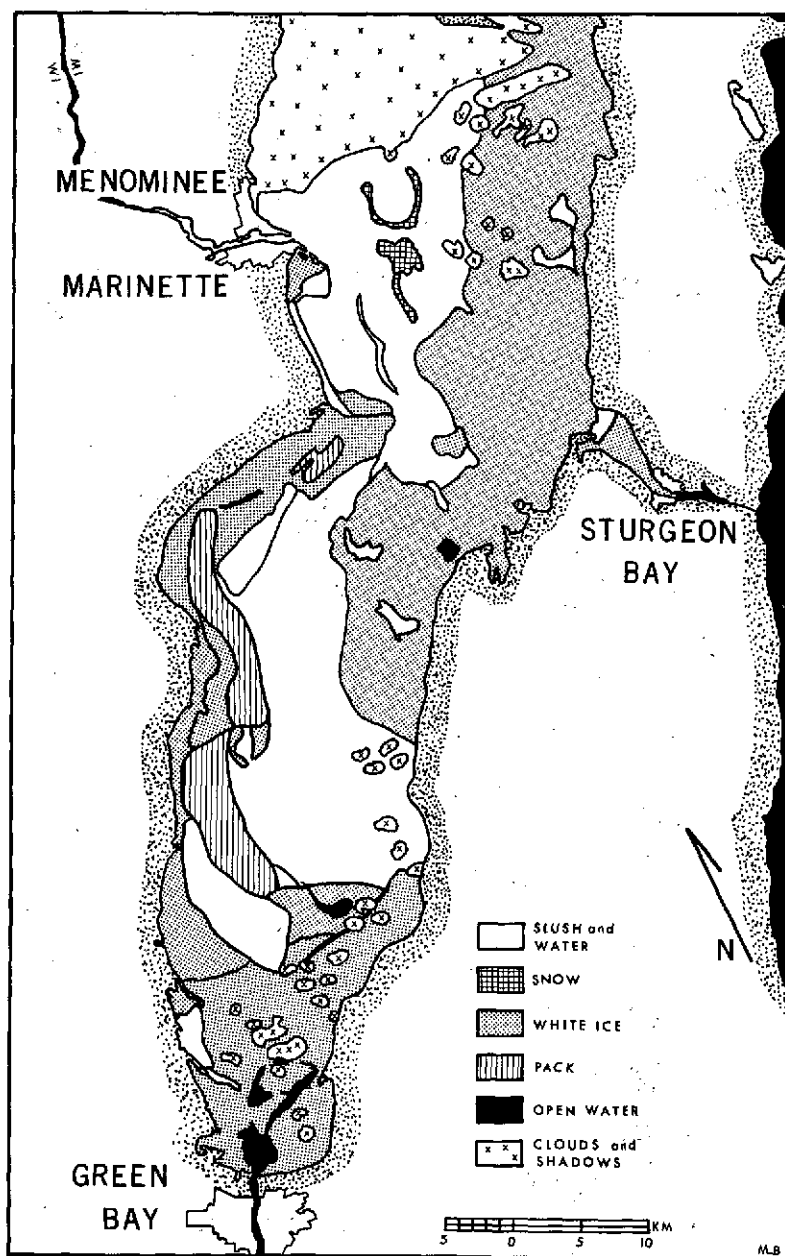


FIGURE 8. INTERPRETATION OF ERTS-1 IMAGERY FOR GREEN BAY, WISCONSIN, 5 Feb 1973. Scene 1197-16095.

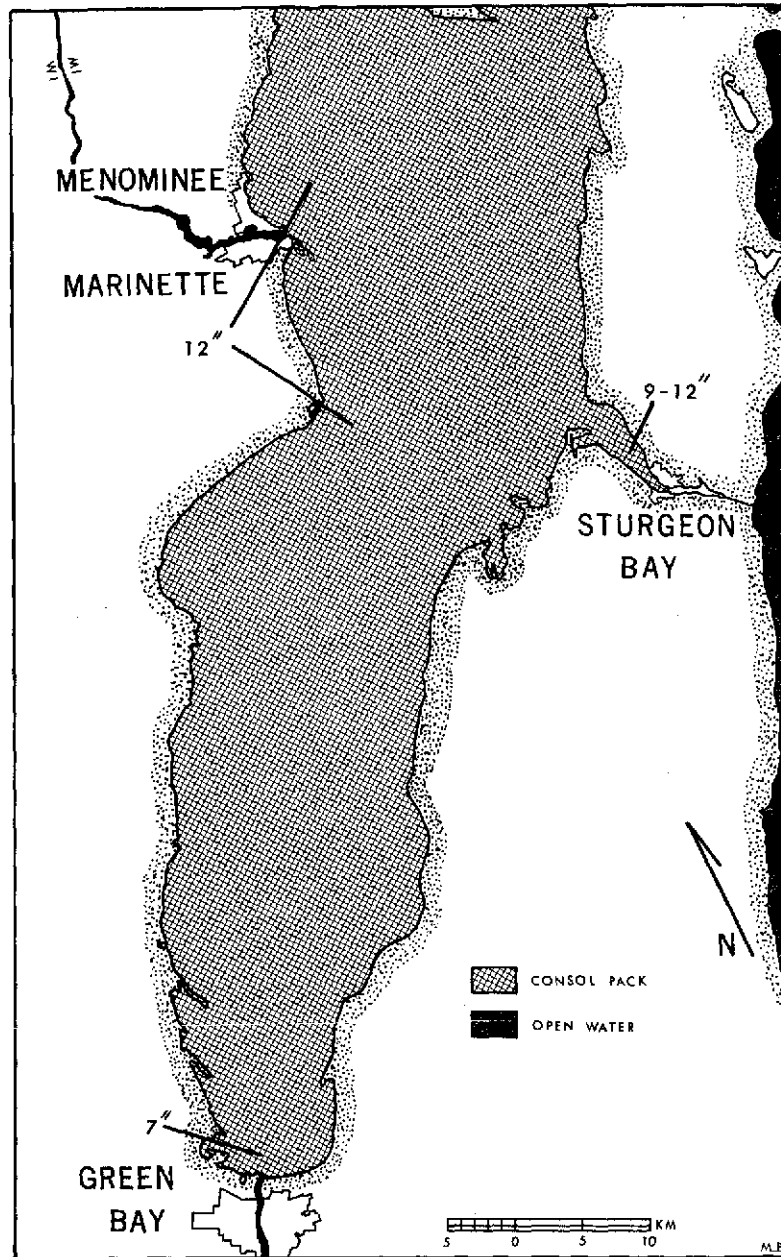


FIGURE 9. ICE ON GREEN BAY, WISCONSIN, 5 Feb 1973.
(Source: U.S. Lake Survey, Detroit, Michigan)

The data presented in this report are interpreted as partially supporting and partially refuting some of the conclusions drawn by other workers dealing with ice and snow problems who used ERTS-1 imagery as a data base.

With respect to snow, it was reported by Carlson (1973a) that Band 5 (0.6-0.7 μm) was best for monitoring snow melt in central Alaska and later Wendler, et al. (1973), reporting on results from the same project, noted that it was best of the four ERTS-1 bands for distinguishing snow-free from snow-covered areas. We must note that these two statements are not equivalent, for the former states only that the snow is melting whereas the latter notes that the snow has melted, and in any case, there is no snow cover in some areas. The data presented in Figure 3 shows only preliminary spectral data for the four ERTS-1 bands for several ice types, and therefore it is difficult to fully support the use of Band 5 to distinguish snow from areas of melting snow. With respect to this problem of melting snow, it would be reasonable to assume that melting snow would have within it a quantity of free water, and it would follow that the Band 7 albedo (0.8-1.1 μm) would be extremely low. Possibly Band 5 does not distinguish melting snow from non-melting snow, but it would appear that the comparison of the two bands (7 vs 5) would be a better discriminator for the melting snow.

Barnes and Bowley (1973a) also support the statements by Carlson (1973a) when they note that Band 5 was best for detection and mapping of mountain snow lines, and that Band 5 was better than Band 4 in that the latter is often "saturated" (overexposed) by snow covered areas. This would seem to state that the snow would be a better reflector in Band 4 than in Band 5. This interpretation is not necessarily supported by the data presented in Figure 3 which shows the albedo of the snow as being apparently equal in all four ERTS-1 bands.

The problem may be, however, more semantic than real, for there are numerous types of snow in the real world and often alpine or mountain snow is, even at its inception, quite different from that formed in the arctic or by mid-latitude winter storms.*

Additional data (Horvath and Brown, 1971) are derived from a multispectral scanner which operated in 12 bands over a spectral range of 0.412-0.852 μm (using the 50% Peak Power Band-pass) and thus do not include data for the ERTS-1 Band 7 (0.8-1.1 μm) spectral range (Tables 4 and 5). It is noted in these data that the spectral radiance decreased at the longer wavelengths. These data were derived from different ice surfaces (both sea ice and fresh-water lake ice), and all quoted in this report are listed by Horvath and Brown (pp. 6-7) as having a moderate, uniform snow cover. No definitions of these terms are offered by those authors. It

*In addition, the metamorphism of snow through time must be considered. See Bader (1954) for a discussion of this process.

TABLE 4. MEASURED SPECTRAL RADIANCE FROM SURFACES WITH MODERATE UNIFORM SNOW COVER.
Spectral Radiance (10^{-3} -cm² -μm - sr). (From: Horvath and Brown, 1971)

TABLE 4(a). Data Collected 16 October 1967

<u>TARGET</u>	<u>TIME</u>	<u>SPECTROMETER CHANNEL</u>												<u>ALBEDO</u>
		1	2	3	4	5	6	7	8	9	10	11	12	
1-1-A	1308	6.977	6.934	6.969	7.053	6.943	6.681	6.474	5.924	5.858	5.945	5.819	3.414	0.73
1-1-B	1308	6.956	6.907	6.965	7.052	6.928	6.667	6.472	5.902	5.833	5.921	5.795	3.382	0.73
1-2-A	1310	6.925	6.817	6.824	6.890	6.757	6.437	6.231	5.666	5.560	5.583	5.415	3.141	0.75
1-3-A	1311	6.758	6.696	6.670	6.776	6.618	6.340	6.178	5.576	5.462	5.520	5.378	3.104	0.74
2-2-B	1349	5.698	5.298	5.184	5.269	4.882	4.686	4.676	4.115	3.965	4.240	4.129	2.564	0.57
3-3-C	1401	-----	5.340	4.976	5.093	4.784	4.369	4.202	3.759	3.641	3.826	3.838	-----	0.62
3-4-B	1402	-----	5.417	5.230	5.299	4.904	4.530	4.422	3.912	3.867	4.091	3.972	-----	0.61

TABLE 4(b). Data Collected 30 September 1967

<u>TARGET</u>	<u>TIME</u>	<u>SPECTROMETER CHANNEL</u>												<u>ALBEDO</u>
		1	2	3	4	5	6	7	8	9	10	11	12	
3-3-C	1122	7.052	-----	6.808	-----	7.059	6.444	6.540	5.793	5.629	5.730	4.842	2.772	0.34
3-4-B	1123	5.567	-----	5.343	-----	5.464	4.864	4.947	4.388	4.161	4.181	3.551	2.073	0.31

TABLE 5. WAVELENGTH RESPONSE CHARACTERISTICS OF THE
12-CHANNEL SPECTROMETER
(From: Horvath and Brown, 1971)

<u>SPECTROMETER CHANNEL</u>	<u>PEAK WAVELENGTH (μm)</u>	<u>50% PEAK POWER BANDPASS (μm)</u>	<u>10% PEAK POWER BANDPASS (μm)</u>	<u>ERTS-1 CHANNEL</u>
1	0.422	0.412 - 0.427	0.398 - 0.431	NONE
2	0.440	0.427 - 0.451	0.423 - 0.456	NONE
3	0.457	0.451 - 0.465	0.446 - 0.475	NONE
4	0.473	0.465 - 0.481	0.458 - 0.487	NONE
5	0.491	0.481 - 0.501	0.478 - 0.508	NONE
6	0.512	0.501 - 0.521	0.492 - 0.536	4
7	0.533	0.521 - 0.548	0.514 - 0.558	4
8	0.563	0.548 - 0.579	0.538 - 0.593	4
9	0.602	0.579 - 0.623	0.566 - 0.638	5
10	0.646	0.623 - 0.674	0.604 - 0.700	5
11	0.710	0.644 - 0.744	0.656 - 0.775	6
12	0.800	0.744 - 0.852	0.725 - 0.920	6

is thus assumed that the spectral response measured in these visible wavelengths are from the uniform snow cover and not from the underlying ice.

Horvath and Brown make several points which are applicable to the present discussion of the ERTS-1 data:

- (a) The spectral radiance varies in the same direction in all channels. This is primarily due to the materials studied (ice and snow) which vary as shades of gray and not as colors.
- (b) In general, for sea ice, radiance at any wavelength increased with the thickness of the ice. (This may also be applicable to lake ice, but no data are available to support this contention.)
- (c) It would appear that snow cover tends to flatten the spectral shape of the radiance curves, as well as to raise its (absolute) level.
- (d) Because the data were collected from an elevation of 600 m, using a ground resolution of approximately 3 m, the effect of the atmospheric attenuation and the extraneous radiation combined to give a net apparent target radiance higher than that which would have been detected by the same instrument at a lower elevation. That is, the energy added by scattering normally exceeded that attenuated by the atmosphere.

This aspect of the elevation effect on radiant energy and its possible effect on the interpretation of ERTS-1 imagery is covered by other ERTS-1 investigators and was not pursued as a part of this project. It should not, however, be a serious consideration when comparing the type of ground truth data used in this report to the ERTS-1 imagery. It is also suggested, however, that the effect for non-machine processed interpretations may be of lesser importance, due to the tendency for the interpreter to quantize the information into fewer groups than are normally handled by the machine processing algorithms (see below).

A comment concerning the term "operational" is needed. Although it is technically possible to produce automatic recognition maps based upon spectral curves from the ERTS-1 data, these data would probably be useful only for scientific and historical, as opposed to operational (near real-time), functions. This is because the ERTS-1 satellite passes over a given area only once each 18 days, its data collection ability may be curtailed by cloud cover (e.g., Fig. 5) and finally because the delay between the time of satellite pass and data collection and its ultimate delivery to the investigator is presently approximately six weeks. This latter problem may, however, be corrected in the future. For more isolated areas or where the immediacy of such information is pertinent, it may be compensated for by the acquisition of a data read-out apparatus operated by the investigators. This possibility is however, very expensive and would be beyond the financial capabilities of most non-government or small government organizations.

3.1.5 CONCLUSIONS TO ERTS-1 STUDIES

The spectral reflections of several types of ice and in the same bands as the NASA ERTS-1 satellite have been presented and used, in a very basic way, to demonstrate their ability for interpretation of fresh-water ice conditions. The study situations are taken from the Great Lakes of North America. Snow covered ice, white ice, slush and water, two types of pack ice, drained slush and open water are identified. However, the purpose of this section is to present the nature of the problem of ice identification from a high altitude, medium resolution (approximately 91 m) satellite system rather than to present definite interpretation techniques. The problem is one which needs considerable additional study. Although all ERTS-1 bands are considered to be of importance in interpreting the data, some bands, and combination of bands, are of greater use than others. Which these are depends upon the ice and snow types being studied. This type of work has limited utility for real-time operational uses (e.g., planning immediate ship movements) while the utility for scientific studies of ice distribution, movement and type identification, is much greater.

3.2 INTERPRETATION OF SLAR DATA OF GREAT LAKES ICE AND SNOW

One of the prime requirements for proper utilization and interpretation of remotely-sensed data and the conversion of raw data into useful and usable information is the collection of ground-truth data. The direct relationship between what is seen visually (but not necessarily perceived) and that collected by panchromatic photography is obvious. A difficulty in the remote sensing field is often the change in perspective of the two views (ground truth vs. remote sensing). With the longer wavelengths of thermal infrared, it is often difficult to relate the views. Our eyes observe one aspect of the scene (i.e., the visible) but the remote sensor detects another (e.g., heat). Small and portable instruments are available to aid us in the collection of thermal data at selected sites (e.g., thermal radiometers, thermometers). At even longer wavelengths, the problems of relating the visible scene and that sensed by the remote-sensing apparatus becomes increasingly difficult (e.g., at the radar wavelengths used (3 and 26 cm) of concern in this portion of the report). In addition, because persons attempting to interpret radar imagery and those providing the ground-truth information are often from diverse backgrounds and training, it is of pressing importance that we proceed to quantify both the ground truth and the remotely-sensed data. Only after quantification will we be able to successfully store, retrieve, and statistically analyze the data and thus properly attack the problem of environmental monitoring and measurement using airborne radars.

The problem is not only the quantification of these data but also the need to make the data collections as simultaneous as possible. If the concern were only for the size, shape, and relative location of buildings, forests, or highways, it would be possible to do the ground truth measurements at any time within several days (or even months) of the remotely-sensed

data collection. Conversely, when dealing with features which are more unstable and ephemeral, it is necessary to make the time lag between the two data collections as short as possible.

Finally, although it is often possible to remove portions of the scene from their natural locations and study them at the laboratory bench, this may subject the sample to changes during collection, storage, and transportation. For example, the collection of a soil sample for later testing can lead to greatly altered structure, porosity, permeability, and moisture conditions, whereas the chemical constituents and, in general, the grain-sized distribution of the sample will have remained unaltered. In the case of snow, time alone is sufficient to alter the physical properties (Bader, et al., 1954). Thus, the nature of the study determines, to a large degree, the nature of the applicable ground-truth which should be used in support of the remote-sensing operation. The organization and conduct of the ground-truth portion of a complete remote sensing study are discussed in several recent papers (J. E. Wilson, 1968; A. S. Benson, 1971).

Numerous papers concerning the interpretation of radar imagery and the nature of radar backscatter from the ground are available (e.g., Innes, 1968; Moore, 1969). There is no need to reiterate these at length. However, it is instructive to simply present the radar equation (Berkowitz, 1966) to illustrate the nature of the parameters affecting the backscatter or reflection of radar waves.

$$P_s = \frac{P_t G_a^2 \lambda^2 \sigma}{(4\pi)^3 R^4} \quad (1)$$

where P_s = received power (i.e., backscatter)

P_t = transmitted power

G_a = antenna gain

λ = wavelength of emitted EM wave

σ = echoing (scattering) cross-section

R = range

Several of these parameters (P_t , G_a , λ) are functions of the radar instrument design and operation, one (R) is concerned with the relative location of the scene to the radar antenna, and the other (σ) is a function of the nature of the target. Basically, the scattering cross-section, σ , is determined by:

- (a) the roughness of the surface relative to λ
- (b) the electrical properties of the material in the scene
- (c) the roughness of any subsurface layers prior to which the attenuation is insignificant (Moore, 1969).

Many studies have been conducted in which both theoretical and empirical measurements of the scattering cross-section are considered (e.g., Cosgriff, et al., 1969). However, there have been few attempts to relate measurements of the surface electrical properties (specifically the dielectric constant) to the radar images.

An example of the type of feature which we are attempting to ground truth and image is given in Figure 10, which illustrates ice in Lake Superior, clearly showing the open water and ice floes. The upper center area also indicates a series of tonal variations on one ice floe. The cause of these variations is unknown because ground truth is lacking and because the panchromatic photography showed a continuous white with no detectable variations in tonal signature across this floe. It is suggested that these variations are old crusted snow surfaces, now presumably buried by more recent drifting and falling snow. Thus, the variations noted on the radar image probably reflect variations in both density and electrical properties throughout the snow drifts. It is also hypothesized that, given the proper conditions, radar could detect moisture changes in snow cover; should this prove correct, it would be of considerable importance in forecasting runoff from hydrologic basins having significant snow cover during the late winter and early spring period. It has been suggested (MacDonald and Waite, 1971) that radars (in this case, K-band) can detect changes in soil moisture over an area; it is also reported that snowfields can be detected on K-band radar imagery (Waite and MacDonald, 1970). The next logical step, it would appear, is to approach the question of quantification of both the ground truth and the radar image in order to prepare these data for machine analysis.

3.2.1 REVIEW OF WORK WITH SLAR

Most active microwave imaging systems that have been developed and flown are designed to operate at a single frequency, utilizing only the bandwidth necessary to realize the range resolution required. These radars have been used for a wide variety of applications, including military uses, cartography, and a variety of earth science studies. The literature contains many applications, both real and potential. For example, uses for radar imagery have been defined for cartography (Crandall, 1969; Gribber, et al., 1971), local geography (Rystrom, 1967; Reeves, 1967), geomorphology (McCoy, 1967) and for ice studies (Rouse, 1969; Johnson and Farmer, 1971). Relatively complete bibliographies listing applications of radar to geoscience are available (e.g., Walters, 1968; Bryan, 1973).

Multi-parameter radar systems have been used to obtain a measure of the cross-polarization (i.e., depolarization) ratio of the back-scattered signal. Because this ratio is strongly dependent upon the electrical properties of the scene (Beckman, 1968), studies and experiments have been conducted attempting to use this ratio to determine additional information about the scattering surface. Such imagery (of the Pisgah Crater, California region)

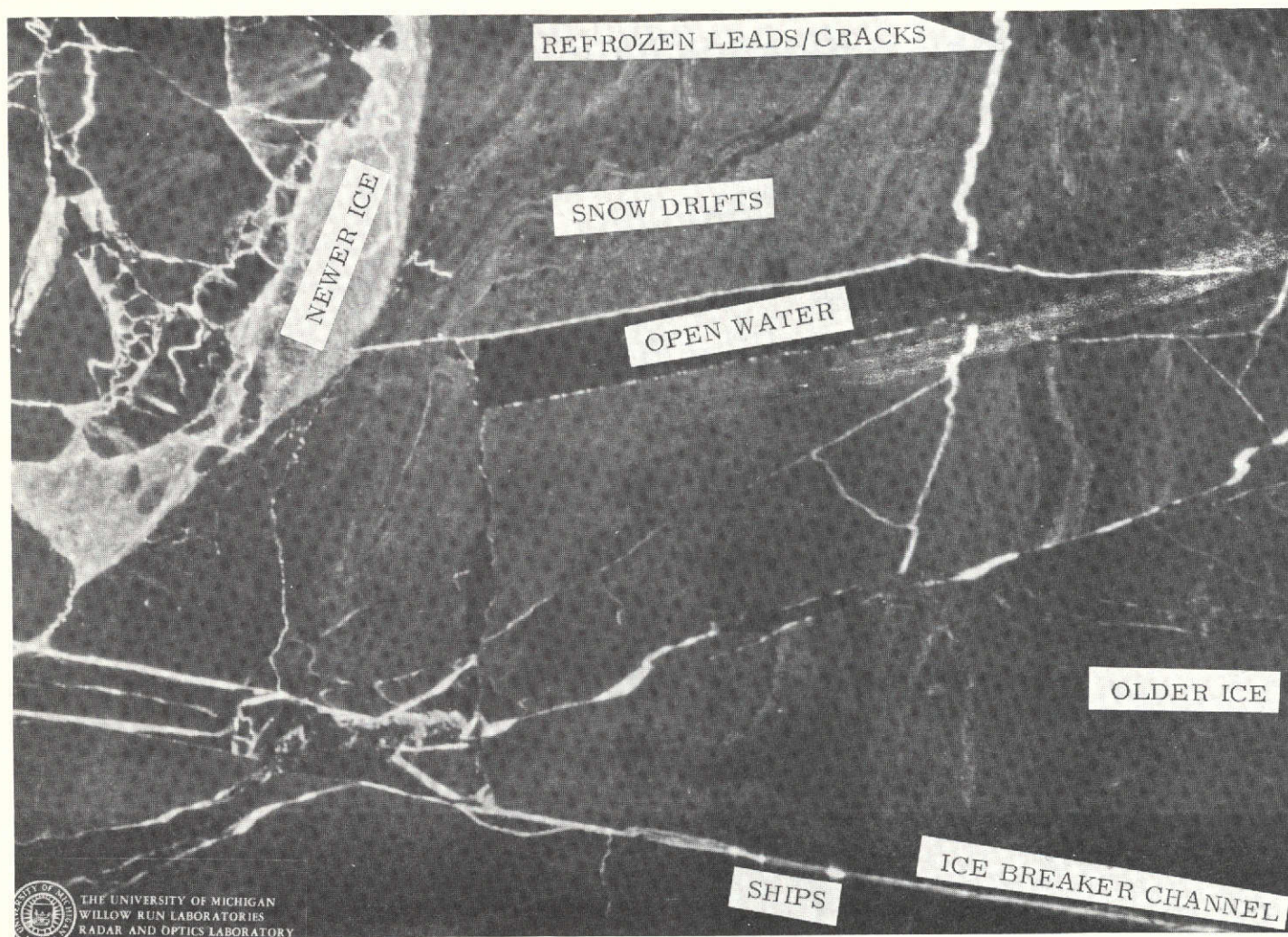


FIGURE 10. RADAR IMAGE OF LAKE SUPERIOR ICE, X-BAND (HH)

has been obtained and studied at various polarizations (Dellwig & Moore, 1966). Geologic studies comparing optical and multi-polarized radar imagery showing such features as faults, fractures, and lineaments are also available (Hackman, 1967; Wing, 1971).

Very interesting experiments have also been conducted using the cross-polarization ratio obtained from radar backscatter from the moon. These experiments provide a measure of the cross-polarization ratio (Q) as a function of the incident angle (Θ_i). The resulting curve (Q vs. Θ_i) is a function of the dielectric constant of the scattering surface (Beckman, 1968). Estimates have been made of the dielectric constant of the surface of the moon using such data.

The lunar radar experiment does not result in a microwave "image" such as we are planning to utilize, but it is clear that the implementation and results are applicable. This is also true of the work reported by Brown (1969) on an experiment designed to study the use of microwave backscattering to determine electrical properties of the earth's surface. The work of Lundien (1965) and Dickey, et al. (1971) is also of importance at this juncture. In both cases, the techniques and results are applicable to our efforts.

Multi-wavelength radar systems have also been used to provide near-simultaneous images from which a measure of the roughness of the scattering surface can be inferred. For example, the U. S. Navy and U. S. Coast Guard have conducted experiments using a four-frequency radar system to identify areas of varying sea surface roughness (Guinard, 1971; Noble, et al., 1969).

It is clear from a consideration of the results of the many related experiments using active microwave sensors that the interpretive potential of microwave imaging radar has not been fully realized. The system parameters to be utilized, in addition to the image of the surface, are (a) multi-wavelengths, (b) multi-polarization, and (c) amplitude calibration. It is expected that by obtaining measurements utilizing as many of the parameters as possible within a single sensor system, considerable additional information can be obtained by conducting the proper analysis of the radar signal. This analysis will require digital computation.

Clearly, the credibility of interpretation of microwave data requires a good foundation based upon proper ground-truth example. This section of the report presents such an experiment and the results from the first phase of a long-term program.

3.2.2 THE RADAR SYSTEM

The Environmental Research Institute of Michigan, under a NASA contract (NAS9-12967) with MSC, Houston, Texas, has developed a synthetic aperture radar system which operated simultaneously at wavelengths of 3 cm and 26 cm, and receives both parallel and cross-polarized signals at both wavelengths. This equipment is presently installed in a C-46 aircraft. Although the system will transmit only one polarization during any given data collection

pass, it may be configured to transmit either with horizontal or vertical polarization. Microwave backscattering data will thus be available to provide four separate images of a mapped area for each aircraft pass, e.g., X(HH, HV) and L(HH, HV) (Porcello & Rendleman, 1972). The radar signal is then converted into an output image by utilizing optical data processing techniques (Cutrona, et al., 1966).

Hardware is available to convert the output map into digital form for analysis. This consists of an image dissector tube to scan the output image and an AD (analog-to-digital) converter whose output is recorded on magnetic digital tape. The software will be designed for each particular data-processing algorithm. Of primary interest in this work will be the cross-polarization ratio obtained for the operating wavelengths. These data are expected to provide the greatest insights into remotely measuring the dielectric constant of the earth's surface materials, and, through analogy, obtaining a measure of the moisture content of those materials.

An additional important capability of the new multi-wavelength, multi-polarization radar is its resolution capability. Resolution as fine as 10 m in both azimuth and range can be realized. Thus, an integral part of the overall objective of the work is to utilize the parameter of fine resolution in the interpretation of the imagery.

The microwave signature will consist of measurements of: (a) the cross-polarization ratio (Q) at both wavelengths; (b) the value of backscattered energy at the two wavelengths S_L and S_X , parallel-polarized (HH, VV); (c) the ratio of the values of S_L and S_X ; and (d) the ratio of the values of Q obtained at the two wavelengths ($P = Q_X/Q_L$). The value of the signature parameters will be obtained as spatial statistical averages over the area of interest. Clearly, this will be obtained using the digital techniques described above.

3.2.3 THE EXPERIMENT

Ultimately, the questions to be answered by means of the information obtained during the complete experiment are:

- (a) Are the ground truthing techniques used adequate? That is, can the ground parameters be determined in the field with sufficient accuracy and consistency?
- (b) Can characteristic signatures of ice and snow types be determined by using the four signatures proposed (X-Band, HH, HV; L-Band, HH, HV)?
- (c) What is the sensitivity of the radar system, i.e., how much variation in the electrical properties and geometrical properties can be recognized with this technique?
- (d) Is this type of data applicable to digitization, digital processing, and automatic interpretation?
- (e) Can analog optical techniques be used in data reduction?

The first phase of the experiment emphasized in this paper is concerned with questions (a) and (b) above. Instruments are available to measure physical parameters of the ice-snow (e.g., SIPRE Snow Kit). In addition, two instruments have been designed and constructed with which to obtain measures of the electrical properties of snow and ice. These instruments provide a measure at both frequencies of operation of the radar and at 100 MHz using a simple Q-meter designed for this application (Figure 11). The Q-meter provides measurements for the control or reference values and also the measurement of fine structure (on the order of a wavelength) of snow and ice used to determine roughness characteristics.

As stated in the introduction to this section, there exists a need to determine particular characteristics of ice and snow for environmental resource studies. Microwave measurements, both active and passive (e.g., Meier & Edgerton, 1970; Schultz, et al., 1964), have been applied to various aspects of the problem with overall encouraging results. In order to evaluate the potential of imagery from microwave sensors, additional imagery is required with (a) pre-flight ground truth for planning, (b) simultaneous ground truth during the flight, and (c) carefully documented post-flight ground-truth data from areas of interest identified on the imagery. A study of some of the existing radar imagery covering ice and snow regions of Lake Superior has shown several interesting features which have not been adequately explained using aerial photographs (Larrowe, et al., 1971 (Fig. 10)). Several possible explanations exist for the observed features. Two particular cases will be discussed.

Case I. The roughness of the scattering surface, defined in terms of the sensor wavelength, determines the magnitude of the backscattered power (Beckman, 1968). The scattering surface is defined as the first discontinuity with the media along the propagation path. The earth-air boundary is usually the scattering surface for the radiation transmitted from an imaging radar system, although there are isolated situations where the scattering surface may not coincide with the optical surface (e.g., dry soil above wet clays). A measure of the reflection coefficient (Ramo & Whinnery, 1958) at a discontinuity can be obtained from a comparison of the relative dielectric constant on each side of the discontinuity. Recall that the index of refraction (η) is related to the dielectric constant (ϵ) by $\eta = \epsilon$ (for air $\epsilon = 1$). The reflection is in excess of 50% for waves incident normal to a surface slope with $\epsilon = 10$, and the reflection coefficient is a function of the polarization. Thus, for values of $\epsilon \lesssim 4$ the reflection is very small and most of the incident energy is transmitted across the boundary to be reflected at the next discontinuity.

Measurements of the relative dielectric constant of dry snow and ice (Evans, 1965; Hoekstra and Spangle, 1972) gives $\epsilon < 4$, so that transmission into the subsurface media can be expected. An estimate of the propagation loss in a material can be obtained from a measure of the loss tangent ($\tan \delta$) of the material. Again, with reference to measurements

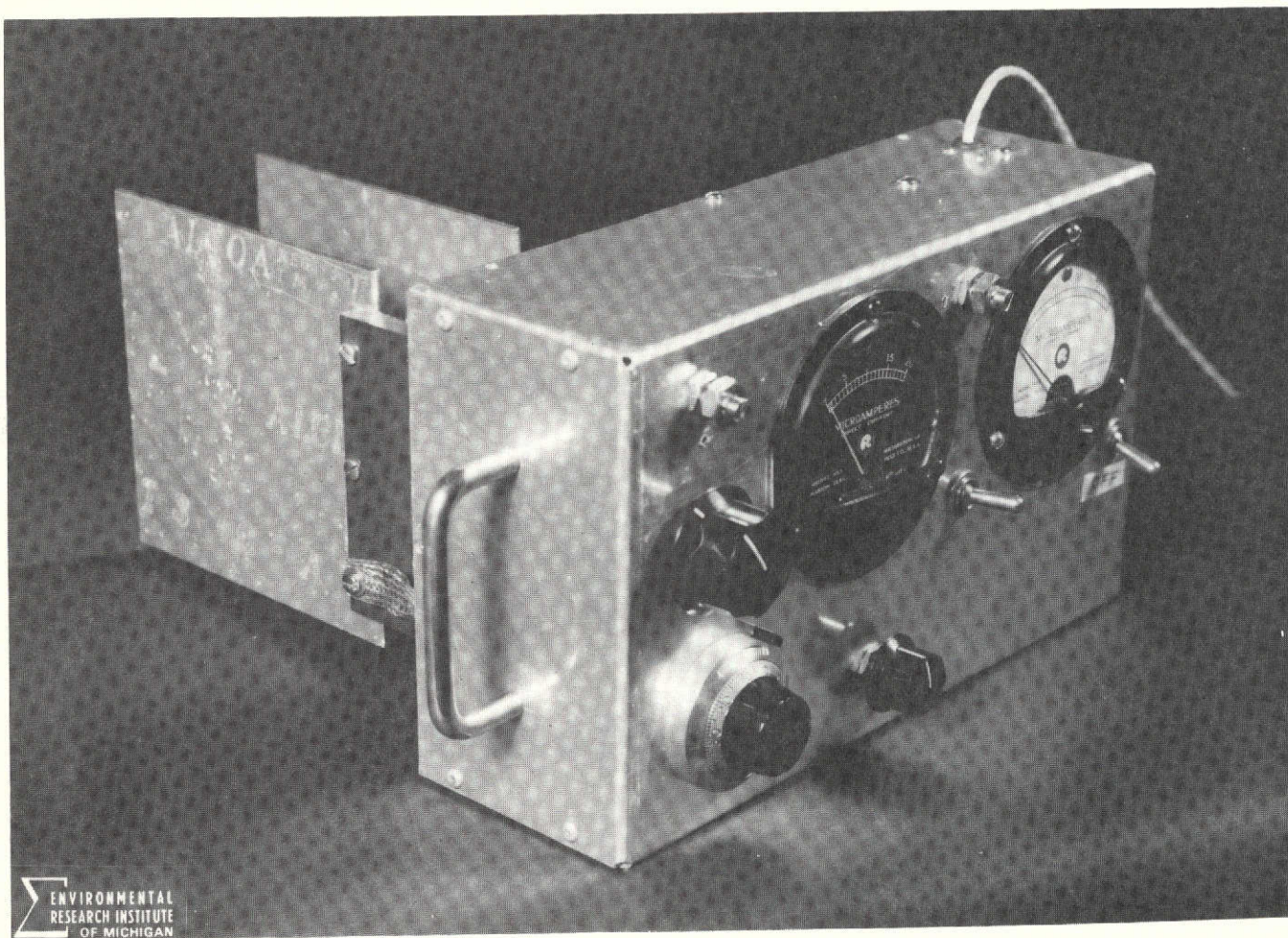


FIGURE 11. PORTABLE Q-METER FOR MEASURING DIELECTRIC CONSTANT AND LOSS TANGENT

made on snow and ice (Evans, 1965), the values of $\tan \delta$ obtained indicate that penetration on the order of meters for 3 cm wavelength is realized, with even greater penetration for the L-Band wavelength. The relationship for the field strength (E) (i.e., the value of the radiation from the radar) at a given wavelength (λ) when propagating in a medium with loss tangent $\tan \delta$ and relative dielectric constant ϵ is given by:

$$E(X) = E_0 e^{-\left(\frac{\pi \tan \delta}{\lambda} \sqrt{\epsilon}\right)X} \quad (2)$$

Examples of measured values of $\tan \delta$ and ϵ for snow are given in Table 6. Values of x_d given in Table 6 are such that:

$$E(x_d) = E_0 \left(\frac{1}{e}\right) \quad (3)$$

An example of results obtained from one series of ground truth measurements for snow is given in Figure 12. Values of density, temperature, and dielectric constant were obtained (on the shaded side of a snow pit) relative to the depth in the snow pack.

A second example of ground truth measurements to be used is given in Figure 13. This is a contoured plot of relative dielectric constant obtained from measurements using the Q-meter described above. The grid is approximately 3×3 m, with samples obtained at intervals of 30 cm. Values given were obtained in new snow about 15-20 cm deep over an ice surface on Douglas Lake, Michigan. Fine-scale measurements can be used to determine the roughness of the dielectric variations.

A second instrument is used to provide a measure of the electrical properties at the frequencies of the imaging radar (approximately 1.3 GHz and 9.6 GHz). This instrument is illustrated in Figures 14 and 15. A solid-state source is provided at both frequencies. Power is coupled through slotted lines, one for each frequency, and then radiated through simple waveguide antennas. The slotted-line sections are used to obtain a measure of reflected power and phase shift when the antenna apertures are placed on the surface of snow or ice. The complete measurement system is mounted in a large metal ground plane, which is supported at each corner to avoid compressing the snow.

Values of reflected power and phase shift can be used to obtain estimates of the electrical properties at the radar operating frequencies. Reduction of the data is realized by obtaining an approximate solution for the radiation admittance of the waveguide antennas when radiating into a homogeneous or layered media of particular dielectric values. This method of measuring electrical properties is similar to techniques used for plasma diagnostics and electron density measurements. Although the technique is not extremely accurate, it will provide a reference measure of the electrical properties at the imaging radar frequencies. It should also be pointed out that the scattering is a volume effect for the situations considered.

TABLE 6. EXAMPLES OF MEASURED VALUES OF
 $\tan \delta$, λ AND ϵ_i FOR SNOW

<u>Temp ($^{\circ}\text{C}$)</u>	<u>λ (cm)</u>	<u>$\tan \delta$</u>	<u>ϵ_i</u>	<u>x_d</u>
-6	3	5×10^{-4}	2	10 m
-	30	10^{-3}	2	60 m

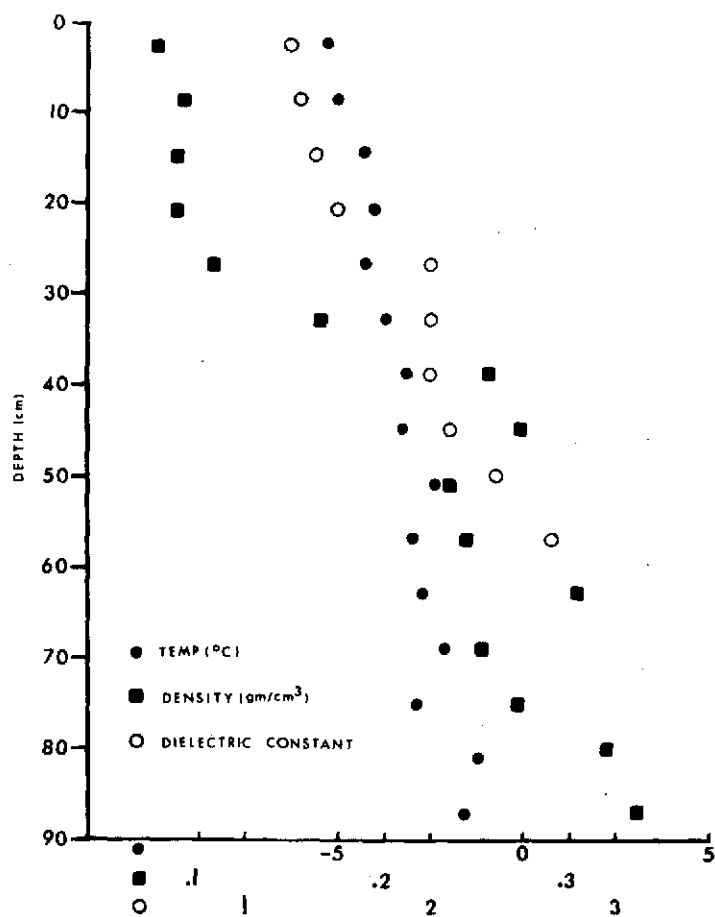


FIGURE 12. PROFILE OF TEMPERATURE, DENSITY AND DIELECTRIC CONSTANT OF SNOW BANK, DOUGLAS LAKE, MICHIGAN, 22 FEBRUARY 1973

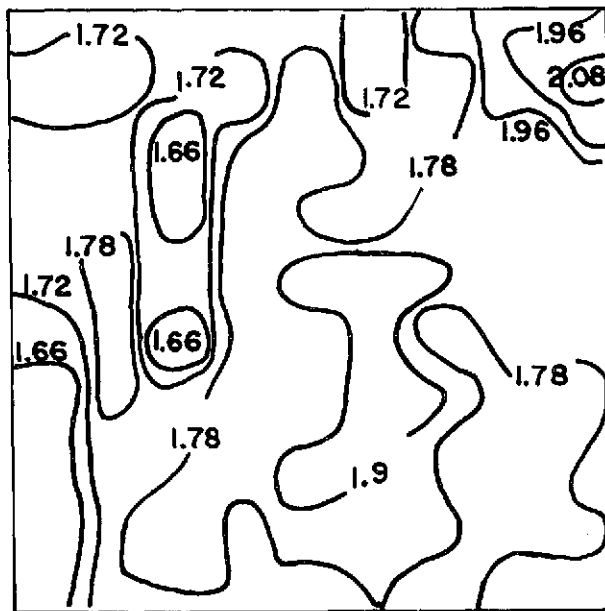


FIGURE 13. CONTOUR PLOT OF RELATIVE DIELECTRIC CONSTANT VALUES, DOUGLAS LAKE, MICHIGAN. 22 FEB 1973. Obtained in a $3 \times 3 \text{ m}^2$ plot in new snow over lake ice.

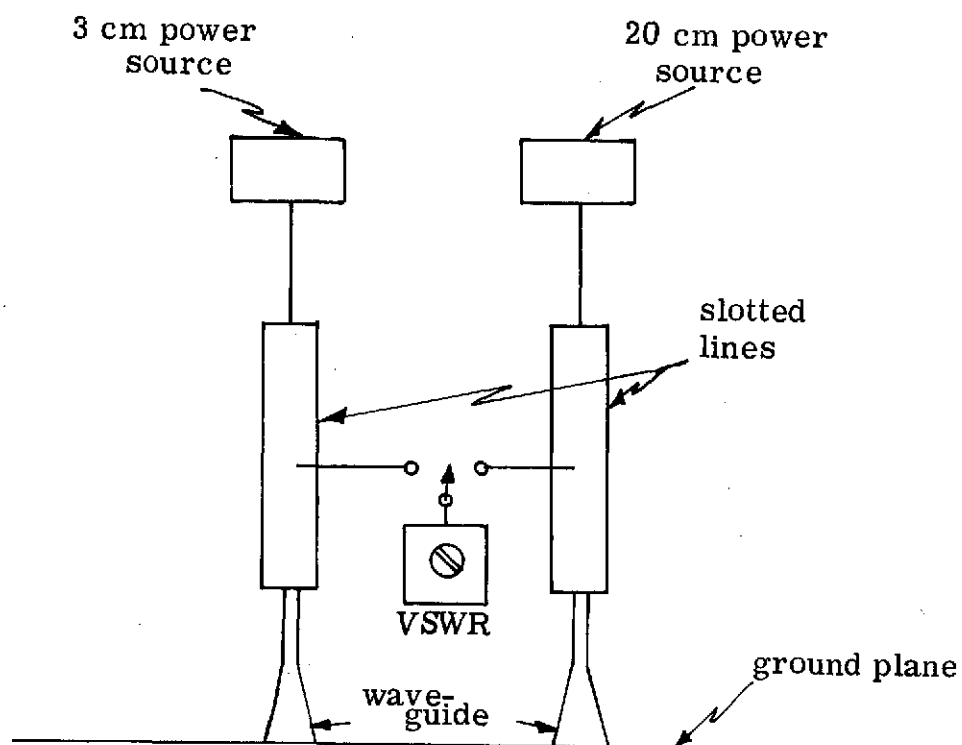


FIGURE 14. DIAGRAM OF INSTRUMENTATION USED TO MEASURE ELECTRICAL PROPERTIES AT WAVELENGTHS OF 3 cm AND 20 cm.

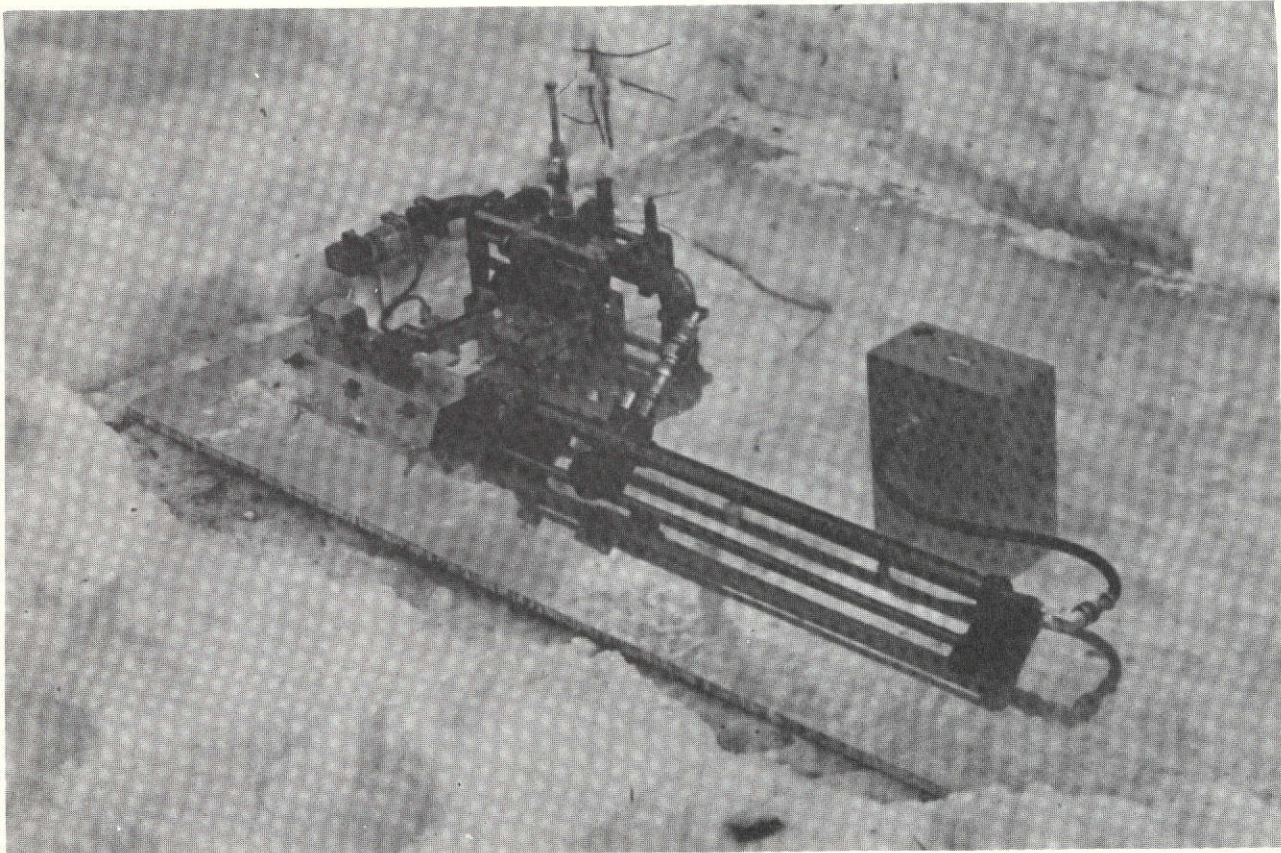


FIGURE 15. INSTRUMENTATION USED TO MEASURE ELECTRICAL PROPERTIES AT WAVELENGTHS OF 3 cm AND 20 cm

By continued and careful ground-truth studies, it is expected that the various structures and features of the snow and ice can be correlated with backscatter characteristics (i.e., the radar image) and used as a basis for interpretation.

Case II. The second case will make use of the cross-polarization ratio (Q) as measured by the radar systems in addition to the roughness characteristics. Ideally, one would want to obtain a measure of Q as a function of angle (θ_i) as discussed above. This can be accomplished to some degree with an imaging radar but requires two or more imaging passes over the area of interest to obtain multiple look angle. This is illustrated in Figure 16, and is similar to a scheme for stereo radar (Laprade, 1963). (It is pointed out, as a matter of interest, that a radar technique that can provide multi-angle looks simultaneously over a fairly wide range of incident angles from normal to 45° is available (Larson, et al., 1971). The field of view of this system is similar to that of infrared and photographic systems.)

Values of the cross-polarization ratio are dependent upon (a) the slopes of the scattering surface, (b) the Fresnel reflection coefficients, and (c) geometry (Beckman, 1968). The Fresnel coefficients are dependent on the dielectric constant of the reflecting material. Measures of Q obtained from the radar measurements when correlated with the radar imagery will "pin-point" the area of interest within the resolution element of the radar.

The objective of Case II is to obtain the polarization characteristic signatures of the various ice-snow types and distribution.

3.2.4 CONCLUSIONS TO SLAR STUDIES

The research scheme in toto was outlined at the beginning of Section 3.2.3, and it was noted that this section of the report is concerned only with parts (a) and (b). That is, can we adequately conduct our ground truth and, if so, can we detect characteristic signatures for the various types of ice and snow of interest? The concern is not only for fresh-water ice (e.g., black ice, white ice, slush, etc.) but also for sea ice (often defined as first year, annual, polar, etc.). As regards snow, the variations in density, moisture content, structure, and depth are all of major importance to persons concerned with predicting stream runoff from snow covered hydrologic basins. An introductory discussion of the variables and problems in such studies is available (Gray, 1970).

The scheme of quantification of ground truth for aid in interpreting imaging-radar remote-sensing data has been briefly discussed. Although we recognize that numerous problems will be encountered, and thus demand solutions, we feel that to continue to concern ourselves primarily with the theory and thus avoid the real-world conditions would be to fail to discover insights into some of the data which are available as radar imagery. It is not difficult to see the obvious parallels between the type of work reported here (and the scheme of which it is a

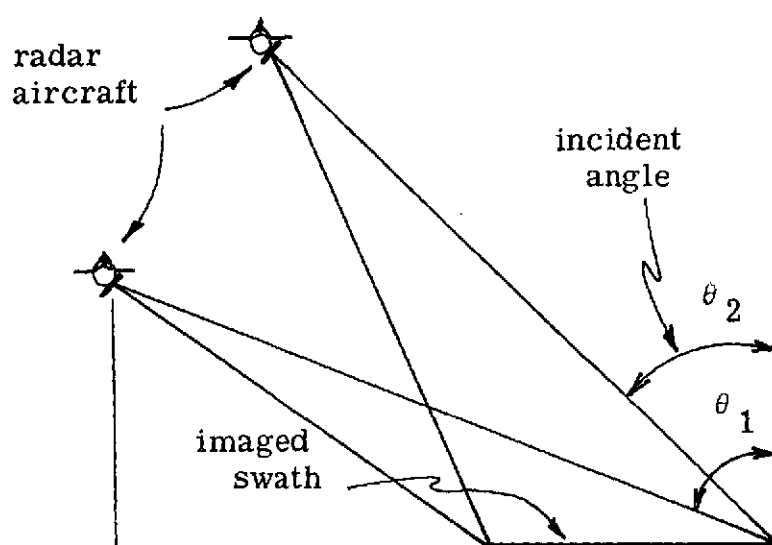


FIGURE 16. SIDELOOKING, IMAGING RADAR GEOMETRY FOR TWO IMAGING PASSES

larger part) and the development of the interpretation of aerial photographic and multispectral scanner data. What makes radar unique is the fact that it is an active system. It also views the world at entirely different wavelengths; these are very long wavelengths which have the ability to penetrate to some depth below the optical (visible) surface and thus identify subsurface structures.

In addition, it is recognized that, with the present rapid rise in the use of remote sensors and the speed with which they are able to collect data and present it to the interpreters, there is a continuing serious problem of a data overload which is entirely beyond the capabilities of human manipulation. Hence, we encounter the problem of machine analysis. This problem has been and is continually being attacked; in many cases, it has been resolved (Rosenfeld, 1969). However, prior to determining the ultimate algorithm for machine analysis of radar imagery, it is obviously necessary to obtain a set of "spectral signatures" from the various surfaces which are of primary interest (Lundien, 1971). In this paper, the application of the method for ice and snow has been the major concern; however, it must be recognized that these surfaces were selected for rather selfish reasons—they closely approach the isotropic plane which geographers often discuss. In other words, we effectively remove much of the surface roughness and are thus able to empirically approach the problem of the effect of dielectric constant on backscattering of radar energy.

3.3 CONCLUSIONS TO ICE AND SNOW STUDIES

For reasons discussed in the summary, it was not possible to obtain simultaneous ground truth and imagery from both ERTS-1 and the dual-frequency, dual-polarized SLAR systems. However, two studies were undertaken to determine the methods of collecting ground-truth data which would be used for the interpretations of such imagery should it become available. Using a small, hand-held radiometer, spectral signatures for six types of ice and snow surfaces were obtained and used in the interpretation of the ERTS-1 imagery of two different scenes. The interpretations, which are based on the assumption that all ice and snow types within the scene are the same as those for which ground-truth (spectral) data were available, shows considerable variation from the ice data normally (visually) collected. This variation is primarily due to different approaches which were taken when the data were collected.

A brief comparison with other data collected with a multispectral scanner similar to that used in the ERTS-1 satellite (but having three times as many data channels and therefore finer spectral resolution) indicate that this approach is valid and can provide field workers and image interpreters with valuable guidance for the interpretation of ERTS-1 data. These ground data also could be used for the development of computer-aided interpretation techniques, although this aspect of the image interpretation was not studied.

With respect to the SLAR studies, it has been suggested that the variations in the electrical properties of snow are possibly sufficient to give multiple reflections from internal layers. The low loss tangent ($\tan \delta$) and the dielectric constant (ϵ_i) indicate that the penetration of active microwave signals at X-Band (3 cm) and L-Band (26 cm) should be in the order of 10 and 60 cm respectively. In addition, it has been suggested that the cross-polarization ratio (Q) for snow surfaces should be instrumental in the measurement of snow moisture content. Preliminary work in this area concerned the design and development of an instrument for collecting ground-truth necessary for the further development of this hypothesis.

Unfortunately, these studies did not get beyond this stage, due to the shift in the emphasis of the entire project from ice and snow studies to those involving lake-shore flooding. It is felt that the work conducted thus far was oriented in the right direction and deserves to be continued.*

To a certain degree the study of these snow and ice surfaces presents a rather unique situation. Penetration of radar energy into the ice and snow will give returns from lower interfaces, and the depth of this penetration is significant, even at these short wavelengths. Similarly, although the resolution of ERTS-1 may be relatively low (especially compared to the SLAR), the comparison of Bands 7 and 5 will clearly indicate the nature of the underlying surfaces when the surface of flooded ice is being considered (as in the case of Green Bay, Wisconsin). Finally, by combining the two systems in concert, the nature of the data concerning these surfaces can be greatly expanded, and the accuracy of inferences concerning their parameters can be increased further than if a much smaller portion of the spectrum were used.

*A more recent paper (Bryan and Larson, 1974) conducted under another contract (NASA 3-18239) concerns continued work in this same vein. The collection and analysis of electrical data from Lake Superior ice in Whitefish Bay, Michigan indicated that, again due to the low dielectric constant ($\epsilon_i = 3$) and loss tangent ($\tan \delta = 110$), penetration of X- and L-Band energy into clear, smooth-surfaced ice would be on the order of 40-50 cm to 3-4 cm respectively. It was further noted in these later studies that the ice was thinner than the L-Band penetration depth, and therefore returns (i.e., backscatter) were received from the lower (ice/water) interface.

STUDY OF MONROE COUNTY, MICHIGAN FLOODING, APRIL 1973

The second portion of this report deals with the comparison and utility of three different remote-sensor systems for the study of fresh-water coastal areas. The three sensors used are: airborne black and white infrared aerial photography, airborne (synthetic aperture) side-looking radar and the satellite-borne (ERTS) multispectral scanner. The operating parameters of these systems are indicated in Table 7.

The major purpose in collecting these data was to determine the interpretability and accuracy of the different sensors and approaches to the study of flooded coastal areas. The nature of the vegetation, the identification of vegetation communities and the rationale or economics of coastal engineering projects are not the concern of this study although such applications may be possible ways of using these or similar data. Consequently, the major presentation will be in the form of interpretation maps which are based on imagery, and in the case of the ERTS-1 data, on digital tapes as well. If it can be successfully demonstrated that such data, processed in a relatively simple manner and visually interpreted, can be easily converted into information which will be of use for local and regional planners, then the effort will be deemed successful. Again, we emphasize that the effort is to demonstrate some uncomplicated methods of applying the data rather than a demonstration of the application itself.

The area of southeastern Michigan comprising the coasts of western Lake Erie in Monroe County is a low-relief Pleistocene lake bed. Many of the coastal areas are marsh and similar wetlands which have been undergoing rather severe erosion. This erosion has been documented by topographic maps and aerial photography for the past several decades. Sattinger, et al., (1972) note that one area, that of Point Mouillee (Figure 17) has been severely eroded during this time period, and that the area has subsequently been diked and converted into a game refuge for migratory waterfowl. Their study briefly describes the development of the game refuge and also defines the several vegetation communities which are found within the diked area.

The other coastal areas under consideration have not been as thoroughly studied with respect to the effect of civil works or flooding, although many urbanized and industrialized areas (e.g., Detroit Beach, Fermi Generator Plant, Stony Point) have been subject to periodic storm and wave damage. This is usually the result of high lake levels (due to spring runoff) and northeast winds which drive the water onto the land.

During the time of the study, rather severe damage resulted from this combination of events. According to the Detroit Free Press (11 April 1973, p. 1), the dikes of Estral Beach were not able to cope with the storms. The first dike had been destroyed by storms in Nov 1972 and the second set of dikes had unrepaired damage. Consequently, as much as 120 acres

TABLE 7. DATA COLLECTION FOR LAKE ERIE SHORELINE STUDY
Monroe County, Michigan, April 1973

SENSOR	VEHICLE	FLIGHT ALTITUDE	OPERATING WAVELENGTH	DATA COLLECTION DATE	RESOLUTION
SLAR	Aircraft	5,600'	X-Band (3 cm; 9.3 GHz) (HH and HV) L-Band (26 cm; 1.165 GHz) (HH and HV)	05 April 1973	30 x 30 ft.
IR Photos (B & White)	Aircraft	10,000 ft.	0.68 μ - 0.951 μ ⁽¹⁾	11 April 1973	(2)
Multispectral Scanner	ERTS-1 Spacecraft (1265-15480)	-----	Band 4 0.5 - 0.6 μ Band 5 0.6 - 0.7 μ Band 6 0.7 - 0.8 μ Band 7 0.8 - 1.1 μ	14 April 1973	approx 300 x 300 ft.

(1) Kodak Wratten Filter 89B and Kodak film 2424 used on K17 camera. (See KODAK, 1971, pp. 3; 52-57 for specifications)

(2) Contrast of 1000:1 has resolution of 80 lines/mm; contrast of 1.6:1 has resolution of 32 lines/mm.

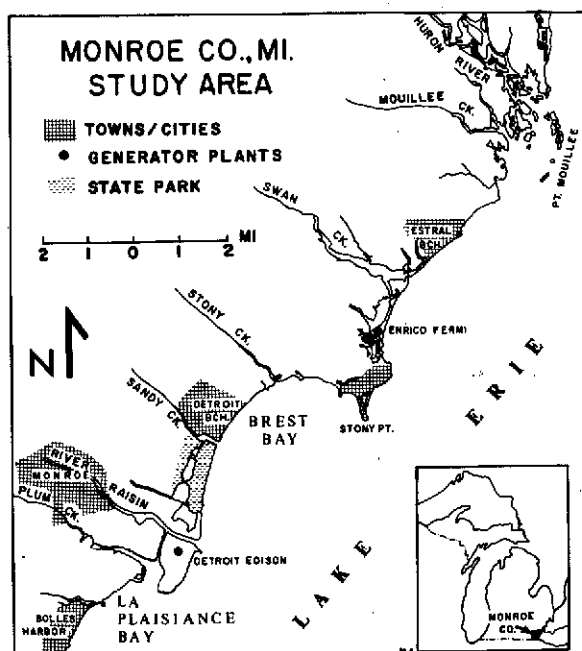


FIGURE 17. INDEX MAP FOR MONROE COUNTY, MICHIGAN

to the north of Estral Beach had been under 8 - 10 inches (20 - 25 cm) of water since November 1972, a condition which was aggravated by the April 1973 storms.

With respect to the April storms, on 8 April 1973 high winds (22 - 30 mph) from the NNE raised the lake 1.5 - 2.5 ft (0.45 - 0.76 m) higher than the already high levels. This was further augmented by rain and snow which contributed slightly to the rise of the water level and rendered rescue and civil defense operations more difficult (Detroit Free Press, 8 April 1973, p. 1). In addition, runoff during this period was above the normal for the time of year, being 60% over the norm for the past 8 years and 125% above the norm for the past 5 years. As a result of these various activities (precipitation, high lake levels, weak dikes and the northeasterly winds), Monroe County experienced a total loss of 30 homes, more than 300 homes sustained major damage and an additional 2500 homes had minor damage (Detroit Free Press, 11 April 1973). The town of Detroit Beach had 18 inches (45.7 cm) of water in its streets and at one time (9 April 1973) most of the 10,000 beachfront residents in Monroe County had to be evacuated from their houses. Within several days, however, all but a few hundred had returned to their properties to pursue clean-up operations.

In economic terms, Red Cross officials noted that these two storms caused considerable damage to all of Michigan. The November storm created statewide damage of approximately \$16 million and the March storm caused approximately \$12 million in damages. Of this latter amount 65%, or \$8 million, was in Monroe County alone. (Detroit Free Press, 11 April 1973). Lake Erie was still 8 inches (20.3 cm) above its previous (1952) record high.

Brazel and Phillips (1974) discuss some of the meteorological aspects of the November 1972 floods, especially with respect to wind speeds and duration and the resulting set-up and seiche actions of Lake Erie. These phenomena are of importance, as clearly illustrated by the differences in lake levels. During the 1972 storm the lake level at the Enrico Fermi Power Plant in Monroe County recorded a 3 foot (0.9 m) rise while at Ft. Erie, Ontario, in the eastern end of the lake, a drop of 4 feet (1.2 m) was experienced.

This means that there was essentially a 7 ft (2.1 m) difference in water levels at the two ends of the lake during this storm period (Figure 18). Even so, 1973 was an atypical year, for this was the first year in a set of records extending over 114 years (as recorded at Cleveland, Ohio) when the lake had a monthly mean elevation above 572.93 ft (174.6 m). This height defines flooding conditions for Monroe County, and is the elevation to which an automatic recording and warning device is set to be activated. Upon reaching this level, county authorities are notified and use this notification to alert the population of the impending danger.

Figure 19 indicates the lake levels at the Enrico Fermi Power Plant for the months of February, March and April, 1973. Also indicated are the annual mean and the monthly means of the lake levels. During the whole of April, when the remote sensing data were collected,

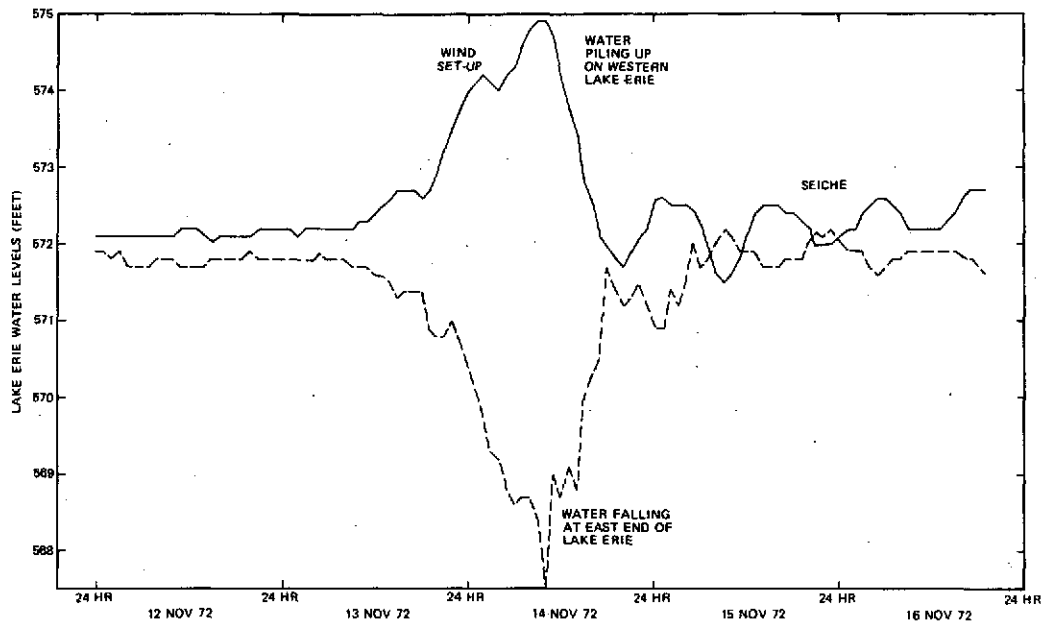


FIGURE 18. WIND SET-UP AND SEICHE ON LAKE ERIE, 12-16 NOVEMBER 1972.
(From Brazel and Phillips, 1974.)

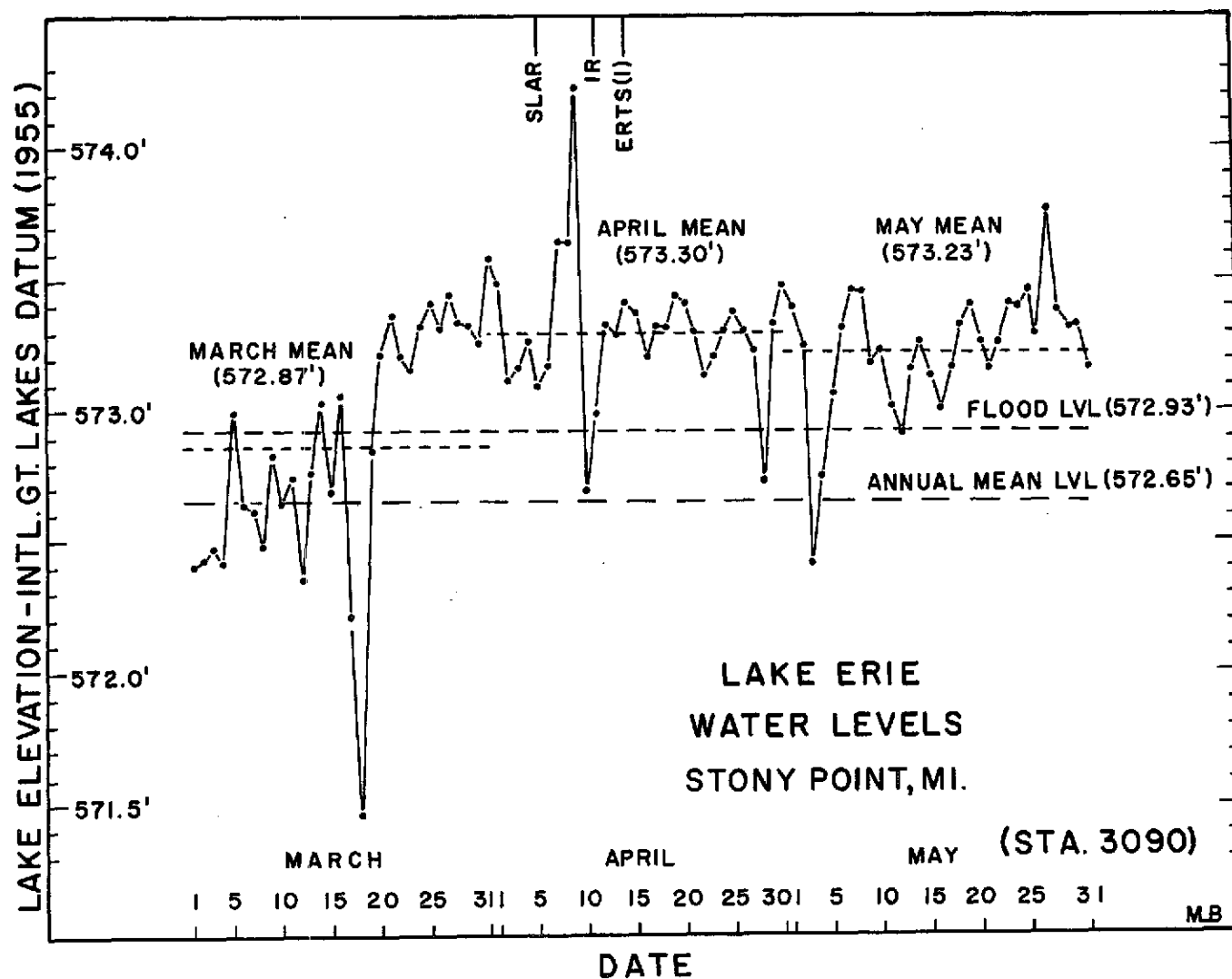


FIGURE 19. LAKE ERIE WATER LEVELS, STONY POINT, MICHIGAN (STATION 3090), MARCH-MAY 1973

the lake in this area was in flood. It is also interesting to note that flood conditions existed for this area from April through to the middle of August, 1973.

The dates of the remote-sensing data collection are also indicated on Figure 19. During the 10-day period when data were being collected, the lake level was always sufficiently high to be considered a flooding condition, although the levels fluctuated by as much as 0.43 ft (0.13 m) during this period. Also during this time, on 9 April 1973 (1500 local time), the maximum height of the lake for the 10 years of record at the Enrico Fermi site was reached. This elevation was 575.83 ft.

4.1 PRESENTATION AND INTERPRETATION OF DATA

For the three remote-sensing data sources the interpretation was in the photo-interpretation mode (Table 8). That is, the imagery was situated on a light table and a tracing, identifying the several themes, was prepared from that imagery.

For both the SLAR and the aerial (IR) photography, five classes were used: open water; built-up areas; wet lands; flooded land; and others. These are defined as follows:

(a) Open water. All areas in which water is the uppermost cover on the land. This includes rivers, lakes, ponds, etc. in addition to fields in which standing water was evident.

(b) Wet lands. These areas may be flooded, in which case vegetation is visible. Thus the term swamp, or marsh, would be applicable. Also included in this category are farm, urban and other (e.g., recreational) areas in which the ground was considered to be at or near the field capacity of the soil.

(c) Built-up areas. Areas which have been urbanized or industrialized, as expressed by the construction of buildings, residential or otherwise. This class does not include highways, transportation networks or similar linear constructions. In some cases it was subdivided into a wet or a flooded urban condition. The "built up" areas consisted largely of small beach front communities composed primarily of residential units and summer cottages interspersed with considerable lawn and open areas. The industrial portion of this category consisted primarily of two large electric generating plants and the associated land uses and services. Only in the southern portion of the study area (in the vicinity of Monroe) was there a land-use which could be properly termed urban.

(d) Flooded. This category was used only with respect to the ERTS-1 imagery interpretations, and is defined as consisting of those areas in which there is standing water on the land.

(e) Others. All other areas (including the linear transportation nets) and lands which were not sufficiently wet to be classed as "wet lands" (see b above).

TABLE 8. IMAGE SCALES USED FOR INTERPRETATION
IN THE MONROE COUNTY FLOODING STUDY

<u>Type of Imagery</u>	<u>Interpretation Scale</u>
B&W IR aerial photography	1:20,000
ERTS-1 - Band 7	1:50,000
SLAR (X and L Bands)	1:31,400 (Cross Track) 1:27,800 (Along Track)

For the ERTS-1 data, the photo interpretation approach identified four classes of land cover: "open water," "flooded land," "wet land" and "dry land." Here, it is noted that the "built-up" category is not included because the sensitivity of the data did not allow the definition of these small areas. Also, the "open water" class and "flood" class are distinguished on these data. This is, essentially, a bifurcation of the "open water" classification used for the IR and SLAR imagery. In both the ERTS and the IR and SLAR imagery, wetlands are comparably defined. The term "dry land" used for the ERTS imagery is essentially the same as the term "other" used for the aircraft data sets.

The reason for this slight difference in terminology is because the data were interpreted by different individuals who had slightly different perceptions of what the working interpretations would be. Also, due to the lower resolution of the ERTS-1 system, it was felt that a change in terminology would help alert readers to this important difference in the data.

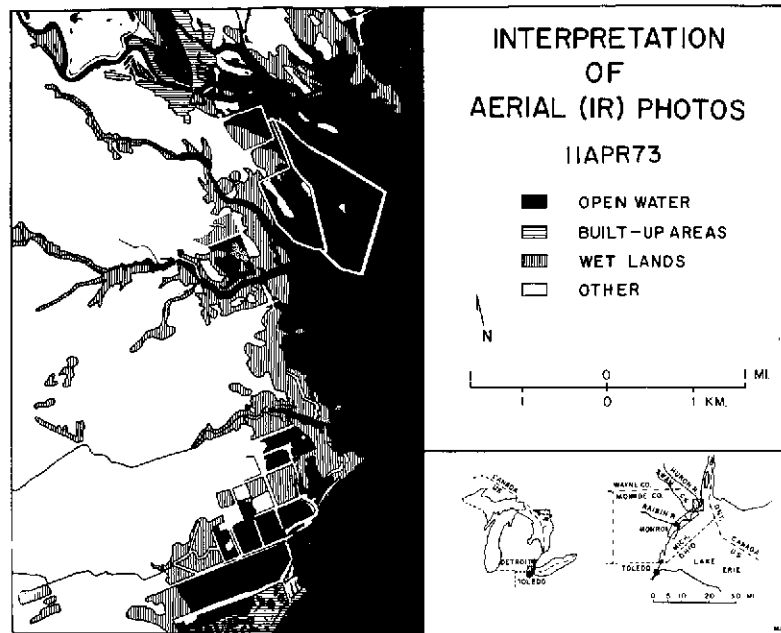
4.2 PHOTO INTERPRETATIONS OF REMOTE SENSING IMAGERY

The interpretations (with the exception of the ERTS-1 slicings) are presented as a set of maps in Figures 20, 21 and 22. Because the area under study is elongated (see Fig. 17) it was necessary to divide the interpretation maps into several sections. Thus, for Figure 20, the sections are, from south to north, (a), (b), (c) and (d). The SLAR data were interpreted independently by two interpreters using the four images available. In each map presentation of these interpretations (Fig. 21) the left portion of the figure is the southernmost of the imaged strip. Two scales are noted for the SLAR interpretation maps. The "cross" scale is to be used in the NW to SE direction while the "along" scale should be used in the SW to NE direction. (The imaging aircraft flew SW to NE, with the antenna beaming to the SE). For mapping of the ERTS-1 imagery, the area was divided at Stony Point; the northern portion of the study area is presented in the left part of Figure 22.

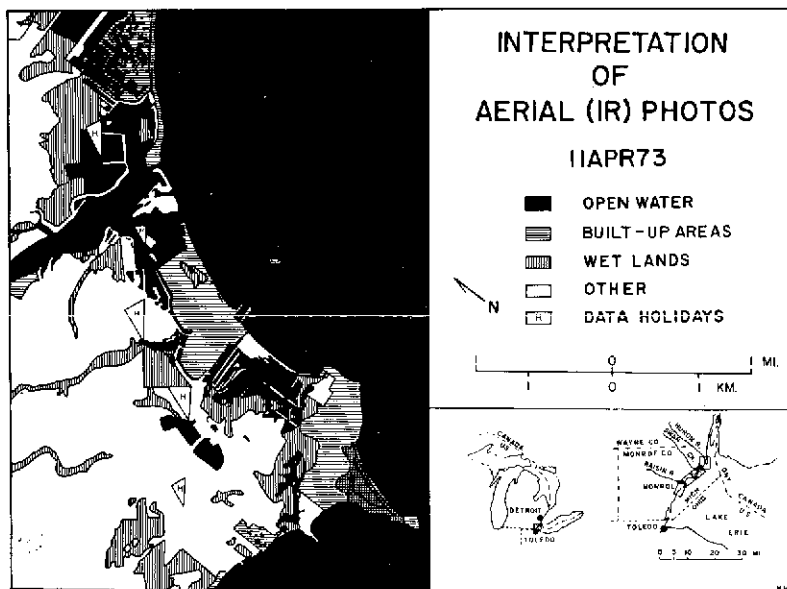
Two different types of comparison were conducted in an attempt to quantify the results. The first method entails the selection of a number of random points on the set of images, the identification of the same geographic points on the other images and a comparison of the classifications of these points on all four images. In this case, specific points, rather than areas, are being discussed.

The second method includes the selection of different geographical areas on the several images and the determination of the percentage of each area which is included in each of the several previously described interpretation categories.

In each case, for such comparisons, one set of data must be used as a "base-set" against which comparisons may be conducted. For these purposes, the B&W IR aerial photography was used because these data have the highest resolution, present greater detail and, due to

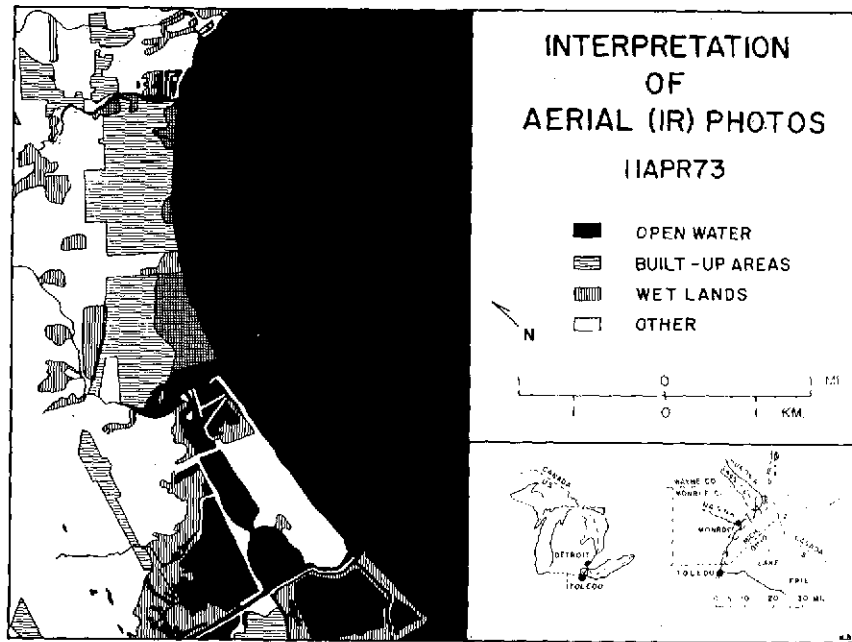


(a)

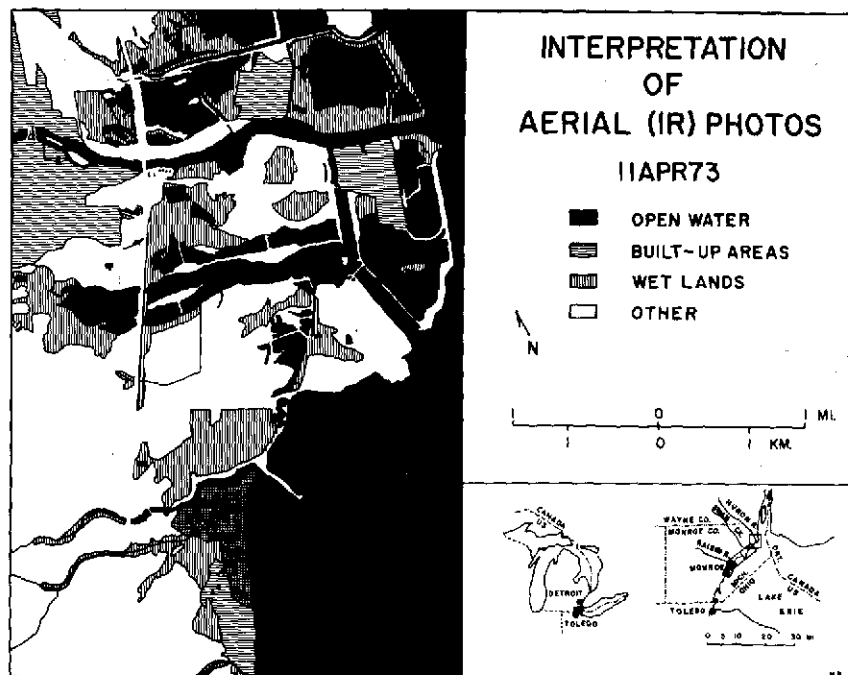


(b)

FIGURE 20. INTERPRETATION OF AERIAL (IR) PHOTOGRAPHS, MONROE COUNTY, MICHIGAN, 11 APRIL 1973 (Continued)

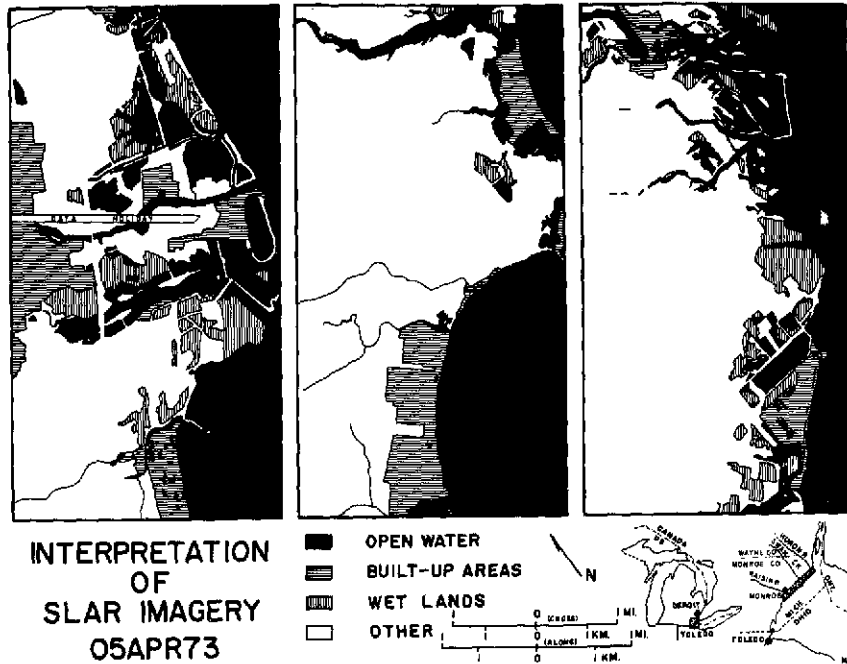


(c)

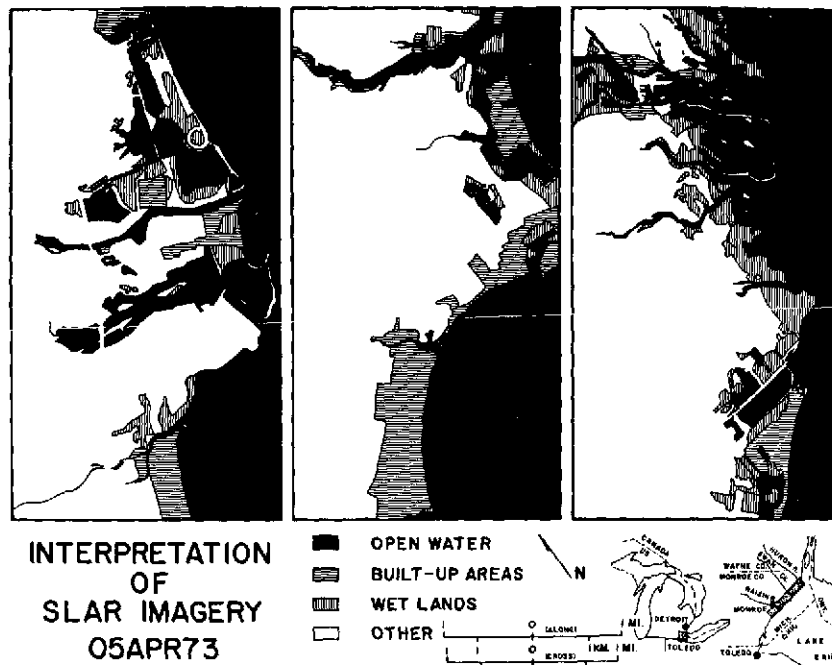


(d)

FIGURE 20. INTERPRETATION OF AERIAL (IR) PHOTOGRAPHS, MONROE COUNTY, MICHIGAN, 11 APRIL 1973 (Concluded)



(a)



(b)

FIGURE 21. INTERPRETATION OF SLAR IMAGERY, MONROE COUNTY, MICHIGAN, 5 APRIL 1973

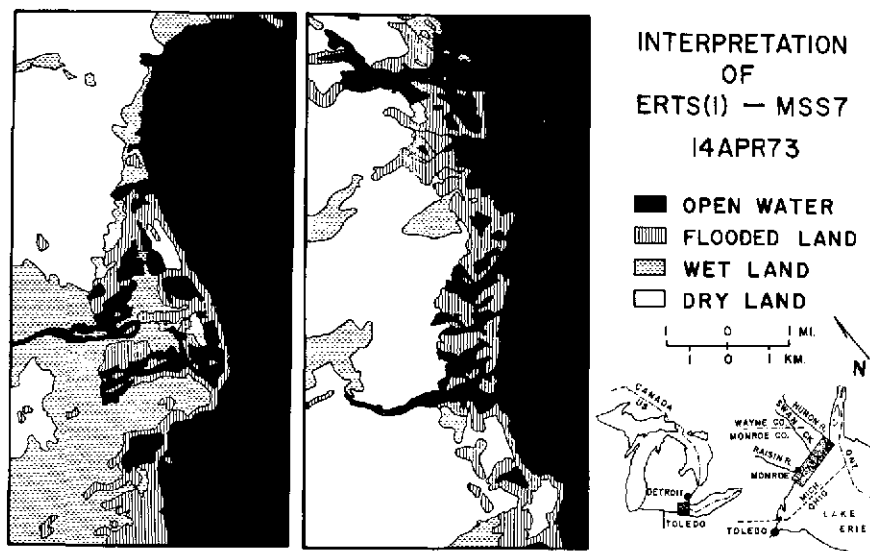


FIGURE 22. INTERPRETATION OF ERTS-1 BAND 7 IMAGERY, MONROE COUNTY, MICHIGAN, APRIL 1973

their historic use by interpreters, probably can be interpreted with higher accuracy. However, it should be pointed out that any errors in the interpretation of the base set of IR photographs will obviously be reflected in the accuracy of the other data sets.

The data presented in Table 9 have been compiled for the first method of comparison, using a set of 170 randomly selected points.

Both SLAR and ERTS-1 Band 7 have a very high degree of accuracy for open water areas, when compared to the B&W IR photography. For the two SLAR interpretations, the accuracy was in the range of 83 - 85% while the visual analysis of the ERTS-1 imagery yielded an accuracy of about 80%. There is no indication in these statements of the minimum size of the area which was being identified, although several water areas which were included within the correct identifications were as small as approximately 40 m in diameter. If we include (from the ERTS-1 interpretations) the category of "flooded land" with that of "open water," the accuracy increases to a high of about 93%. In other words, 43 of the 46 locations were correctly identified.

For both of the SLAR interpretations, the built-up areas were correctly identified 63% of the time (10 of 16 locations). Built-up areas were identified as "other" 44% of the time (7 of 16) on the ERTS-1 imagery, this being the only logical classification into which they would fit.

"Built-up and wet" areas, that is, those which were built-up and also experiencing flooding or soils at field capacity, were generally interpreted as "flooded" on the ERTS-1 imagery and were also easily identified as "built-up" (90-100%) on the SLAR data. They were not, however, generally identifiable as being flooded or wet on the radar imagery.

The interpretation of wet lands was relatively poor, only 32% accurate for the ERTS-1 Band 7 and 45 - 50% accurate for the SLAR interpretations. This rather low performance is not too surprising because these areas were normally covered with some type of vegetation which would mask the soil surface. Thus, it would probably be better to study the ERTS-1 Bands 4 and 5 ratio (i.e., vegetation discrimination) and then to further compare this ratio to the Band 7 interpretations to further discriminate the vegetated areas from those being identified as wet. This combination may identify those vegetated areas having soils at field capacity, or in the present terminology, those identified as "wet."

A similar argument may be given for the interpretation of the wet areas using the SLAR imagery. Although the ground was at or near the field capacity, the vegetation could cause some energy returns and thus contribute considerably to the rather low accuracies (45-50%) experienced with this imagery. It must be stressed that for the SLAR interpretation, all four sets of data were used simultaneously, with the cross-polarized imagery (HV) proving to be most helpful for the identification of the wet fields.

TABLE 9. COMPARISON OF ERTS-1 AND SLAR IMAGERY INTERPRETATION TO B & W IR PHOTOGRAPHIC DATA. Number of correct identifications are indicated. Percentage of correct identifications in parenthesis.

	B&W IR	SLAR				SLAR				ERTS 1 BAND 7			
		OPEN WATER	BUILT UP	WET	OTHER	OPEN WATER	BUILT UP	WET	OTHER	OPEN WATER	FLOODED	WET	DRY
OPEN WATER	46(100)	38(83)	1(2)	4(9)	3(7)	40(87)	----	4(9)	2(4)	37(80)	6(13)	2(4)	1(2)
BUILT-UP	16(100)	---	10(63)	1(6)	5(31)	-----	10(63)	4(25)	2(13)	-----	3(19)	6(38)	7(44)
BUILT-UP WET	8(100)	1(13)	7(88)	----	-----	-----	8(100)	-----	----	-----	5(63)	3(38)	-----
WET	44(100)	3(7)	1(2)	20(45)	20(45)	4(9)	2(5)	22(50)	16(36)	5(11)	18(41)	14(32)	7(16)
OTHER	56(100)	1(2)	4(7)	4(7)	47(84)	-----	4(7)	3(5)	49(88)	4(7)	17(30)	14(25)	21(38)

"Wet" areas, as identified on the IR photography (that is, all wet land not also classified as built-up), were commonly identified as "wet" approximately 50% of the time on the SLAR imagery, and, as a combination of "wet" or "flooded" approximately 75% of the time on the ERTS-1 Band 7 imagery. "Other" on the infrared photography is also so classified on the SLAR imagery 85 - 88% of the time while, with respect to the ERTS-1 imagery, such areas were classed as "flooded wet" in 55% and as "dry" in 58% of the identifications.

The interpretation accuracies of the data presented above lead to several conclusions with respect to the usefulness of the several data sources for mapping flooded and inundated land during the flooding condition. Both sensors, when compared to the B&W IR photography base data have comparable accuracies for the identification of open water. ERTS-1 is, however, a better sensor if we consider that it was possible to define both open water (ponds, lakes, rivers, etc.) and flooded fields (that is, standing water) within this category. By adding these two categories together, the ERTS-1 imagery has an accuracy of 93% whereas SLAR, in which the category "open water" includes the flooded fields, has an interpretation accuracy of between 83-87%.

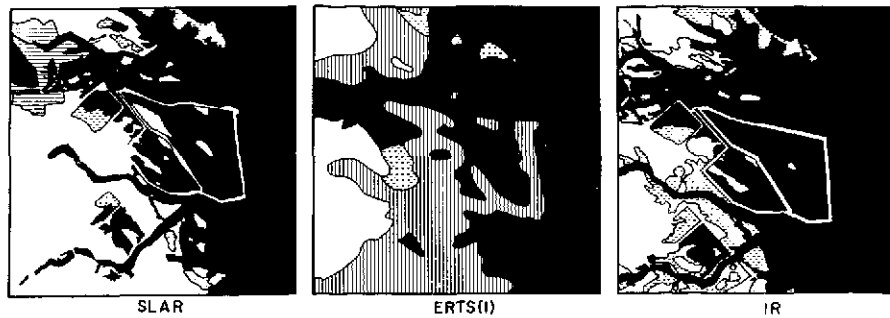
Comparison of interpretation of the built-up and built-up/wet areas is quite difficult, primarily due to the different approaches used by the several interpreters and the lack of identification of the built-up areas with the ERTS-1 imagery. Consequently, although these areas are easily identified on the IR imagery, they should be sub-divided for present purposes. For the SLAR interpretations, the built-up and wet areas were easily identified as built-up (89 - 100% accuracy) but not as wet. This is probably a function of the areas selected and the fact that for the comparisons, points rather than areas were used. One SLAR interpreter did, in fact, detect open water within the built up areas (Fig. 21a). Again, on the ERTS-1 Band 7 imagery we note that areas of built-up and wet were accurately identified as flooded and/or wet 100% of the time. This would imply that even for built-up areas ERTS-1 Band 7 can provide useful data set for the identification of flooding conditions. In fact, for this category, the accuracy of ERTS-1 interpretations was higher than it was for the wet and also non-built up areas. Thus by combining the two sensors, using the ERTS-1 to identify the wet areas, and then the SLAR for identifying the built-up (urban) areas and subtracting one from the other, we would be able to obtain a very good indication of the areas which are both built-up land and are undergoing flooding. The importance of this should not be lost. When it is recognized that both of these data systems may be operative from spacecraft with no degradation in the resolution used in this study, it is apparent that this combination could be a very powerful sensor set for the study of flooding conditions and the direction of post-disaster operations. The major problem is, of course, the weather dependency of the ERTS-1 satellite imagery and the fact that, should clouds persist over the flooded area for a considerable period following the flooding, the data would be unavailable until so much time had elapsed that their use

would become a rather moot question for such work. (Conversely, it must be noted that aircraft data collection of the "base" sensor data - that is B&W IR photography - may be possible during such clouded periods. The problem here would be the limited coverage and the fact that it would be rather difficult to take this into the automatic interpretation mode - a necessity for near-real time operational tasks on a state-wide basis.)

Lands interpreted simply as wet, which are those interpreted as having a soil moisture content at or very near field capacity, were only moderately well identified on the two sets of imagery. For SLAR interpretations, accuracies on the order of 45 - 50% were obtained, whereas for the ERTS-1 imagery the interpretation accuracy was as low as 32%. The data in Table 7 would indicate that it is probably better to utilize other ERTS-1 bands (specifically Band 5 (0.6 - 0.7 μ m) and Band 6 (0.7 - 0.8 μ m)) for the study of wet areas. This is because of the lower accuracies indicated for this classification from the ERTS-1 Band 7 and the fact that a portion of the spectral range of the IR photography (0.68 - 0.8 μ m) was not represented on the ERTS-1 Band 7 imagery. Thus, the spectral range and the lower resolution of ERTS-1 were probably combined to give these low accuracies.

Also of interest is the fact that the SLAR had a slightly better interpretation accuracy for the wet lands than did the ERTS-1 imagery. It has often been suggested that SLAR would be useful for mapping flood plains, especially during and shortly after the flooding. The arguments are that during the flooding the smooth water would act as a specular reflector and the SLAR image would consequently be black in the flooded areas. For the period immediately following the flood, the high moisture content would render the soil as a very poor reflector and a good depolarizer of the microwave energy. Our analysis of the imagery of such areas does not, at present, support SLAR's viability as an accurate data source for mapping flooded areas immediately following the initial recession of the flood waters. (A different conclusion, in a similar context was, however, reached by MacDonald and Waite (1971), who noted that dual-polarized K-Band radar imagery allowed the qualitative estimate of soil moisture content.) The problem of vegetation cover remains a major problem for these studies.

The second approach to the comparison of the three data sets was to determine the percentage of a given area which was classified in each of the categories by each of the sensors. In this portion of the study, only one of the SLAR interpretations was used because the two previously used were nearly identical. The three areas selected for study were Pointe Mouillee, La Plaisance Bay, and Estral Beach (Figure 23). The data were collected by determining the numbers of units in a grid pattern for each of the map themes as a percentage of the entire area covered by each map. It should be noted that the areas included in Figure 23 are not perfectly congruent with the sub-set of the data used for such areas measurements. One unit of measured data in this portion of the study covered approximately 0.95 acres (2.35 HA).



(a) Pointe Mouillee



(b) Estral Beach



(c) La Plaisance Bay

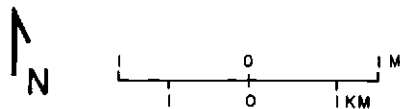
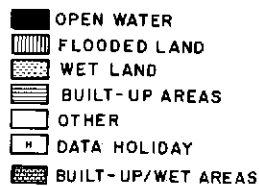


FIGURE 23. INTERPRETATION MAPS OF COASTAL AREAS, MONROE COUNTY, MICHIGAN, APRIL 1973

Again, if the B&W IR interpretation map is used as the basic data set to which the other interpretations are compared, we note that the IR data consistently identified a larger portion of the area as open water (Table 10). The under-measurement of open water varied from a low of 17% (Estral Beach, SLAR) to a high of $\pm 0\%$ (La Plaisance Bay, SLAR). It must be emphasized that when making these comparisons, we considered the percentage of area covered by the various categories rather than the actual number of units covered. This is because the scales of the several maps, even though closely rectified for this portion of the study, were not totally congruent.

The earlier comment with respect to the "flooded" class being a division of "open water" on the ERTS-1 imagery leads to some very confusing results, for by combining these two classes for the ERTS-1 imagery an over-evaluation of the "open water" class is produced. This over-evaluation varies from +17% for the Pointe Mouillee site to +22% for the other two study areas.

It is apparent that the ERTS-1 imagery identification needs refinement beyond that conducted by the visual interpretations. The flooded land is not simply a division of the "open water" and "wet land" categories, but is a category consisting of both the open water and the wet lands. For example, Figure 23(b) indicates that for the Pointe Mouillee case much of the land is classed as open water by ERTS. These are primarily areas of small islands, dikes and similar areas which are not sufficiently large or reflective to be recorded within the resolution cell of the satellite multispectral scanner. In the southern portion of the Pointe Mouillee study site, the reverse is observed, where many water areas are too small to be detected by the ERTS-1 system. These areas probably reduce the spectral response in MSS-7 and sufficiently darken the cell to yield a darker grey tone which is interpreted (visually) as flooded lands on the ERTS-1 imagery interpretations.

With respect to the classification of wet areas, the data for ERTS-1 are rather inconclusive when compared to that for IR. In the case of Pointe Mouillee, interpretation of the IR data had approximately 4 to 7 times more "wet" area than did interpretation maps of the other two data sets. However, for the Estral Beach study area the IR indicated approximately 4 times as much water as did ERTS-1 and only slightly less than was indicated on the SLAR data. For the La Plaisance Bay area, IR and SLAR indicated very similar areal coverage (11 and 9% respectively) whereas ERTS-1 interpretations were approximately three times higher (32%). (See the above discussion with respect to the open water in this area.)

For the urban and built-up areas, only two of the three sensors were usable because the very small urban settlements were not identified on the ERTS-1 imagery. We note that the areas identified as urban in terms of percentage of the area covered were easily identified. For the La Plaisance Bay study site, an attempt was made to separate the built-up area into

TABLE 10. PERCENTAGE OF AREA IN EACH GROUND SURFACE CATEGORY
FOR THREE COASTAL STUDY SITES

		OPEN WATER	FLOODED	WET	BUILT UP	OTHER	HOLIDAYS
Pointe Mouillee, Michigan	IR ($\Sigma = 2907$)	1922 (66)	---	439 (15)	2 (.LT.1)	544 (19)	--
	SLAR ($\Sigma = 2793$)	1598 (57)	---	121 (4)	15 (1)	1059 (38)	--
	ERTS (1) ($\Sigma = 3306$)	1755 (53)	1006 (30)	82 (2)	--	463 (14)	--
Estral Beach, Michigan	IR ($\Sigma = 3249$)	1623 (50)	---	375 (12)	263 (8)*	978 (30)	10 (.LT.1)
	SLAR ($\Sigma = 2850$)	950 (33)	---	408 (14)	212 (7) ⁺	1280 (45)	--
	ERTS (1) ($\Sigma = 3306$)	1528 (46)	866 (26)	112 (3)	--	800 (24)	--
La Plaisance Bay, Michigan	IR ($\Sigma = 3249$)	1481 (46)	---	358 (11)	94 (3) [¢] 144 (4) [#]	1172 (36)	--
	SLAR ($\Sigma = 3078$)	1136 (46)	---	275 (9)	275 (9)	1432 (47)	--
	ERTS (1) ($\Sigma = 3306$)	1394 (42)	866 (26)	1046 (32)	--	--	--

Notes: * includes 153 (4) areas of standing water

+ includes 41 (1) areas of standing water

¢ Built Up only

Built-Up/Wet category. Includes: 65 built up; 79 standing water

two sub-categories of "built-up" and "built-up/wet." These data essentially split the urban area into two even subsets.

For Estral Beach, the areas identified as built-up were comparable, with 8% for the IR imagery and 7% for the SLAR data. Within these areas, however, the radar data measured considerably less standing water than was determined on the IR imagery (1% vs. 4%). Put another way, of the 263 units identified as "built-up" on the IR imagery, 153 (54%) were identified as "open water," whereas only 19% of the total built-up areas were classed as "open water" for the SLAR imagery. Similar data are clearly available from the La Plaisance Bay study site with respect to the IR and SLAR interpretations of the "built-up/wet" areas.

4.3 STUDY OF ERTS-1 COMPATIBLE TAPES

When using simple level-slicing techniques for the analysis of computer compatible tapes (CCT) such as are available for the ERTS-1 data, a variety of approaches may be made.

Initially, the three scenes of interest in this coastal study were studied by two different level-slicing techniques. The first consisted of dividing the entire data range (000-042) into eight equal groups. (Because the data are in integers, the several groups cannot be of exactly equal size.) The results of this slicing, presented as digital gray maps, are presented in Figure 24.

The second approach was to divide the data so that each group would contain 10% of the entire data set. Again, due to the fact that the data are stored as integers, these groups, especially the second, are not of equal size (Figure 25, Table 11). Both of these slicings were conducted using the Band 7 data of the Lake Erie shoreline of Monroe County. The entire area included on the tape (covered by the ERTS-1 interpretation map, Fig. 22) consisted of 65,000 data cells.

In these approaches, the data were simply divided into discrete subsets according to a pre-determined scheme. These subsets were then printed to provide the gray maps, but the technique itself does not discriminate any types of land-use of earth surface categories, nor does it really provide any type of analysis which would be helpful for the study at hand.

However, for our purpose, which was the identification of specific land uses or ground-truth criteria, three quite different approaches may be made.

- a) The first approach involves knowing the signature of the several ground surfaces. These data are collected in a manner similar to that discussed in Section 3.1.1. Although the visual, photo-interpretation method was used in the examples of this approach, use of such signatures is easily compatible with automatic interpretation techniques using ERTS-1, CCT.

TABLE 11. AREAL COMPARISON OF THREE COASTAL STUDY AREAS, USING DENSITY SLICINGS FROM ERTS-1 COMPUTER COMPATABLE TAPES - BAND 7.

Table 11a 10 Gray Levels - Histogram

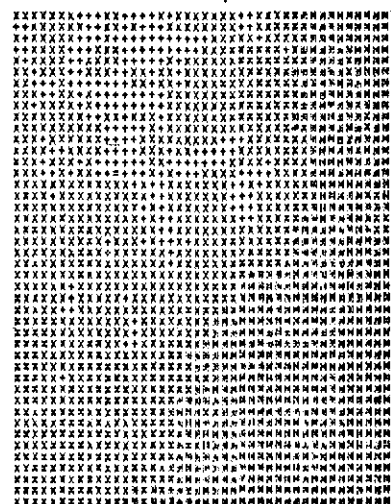
DATA RANGE	POINTE MOUILLEE		ESTRAL BEACH		LA PLAISANCE BAY	
	NUMBER POINTS	PERCENT	NUMBER POINTS	PERCENT	NUMBER POINTS	PERCENT
000 - 001	0	0	10	0.5	28	1.2
002 - 002	50	2.6	128	6.6	608	27.5
003 - 003	86	4.5	164	8.5	426	19.2
004 - 006	159	8.2	242	12.5	90	4.1
007 - 013	340	17.6	293	15.1	221	10.0
014 - 015	159	8.2	194	10.1	117	5.3
016 - 017	368	19.0	313	16.2	225	10.2
018 - 018	305	15.8	148	7.6	113	5.1
019 - 020	208	10.8	198	10.2	194	8.8
021 - 042	253	13.0	244	12.6	187	8.5
Sum	1932	99.7	1935	99.4	2209	99.9

Table 11b 8 Gray Levels - Linear

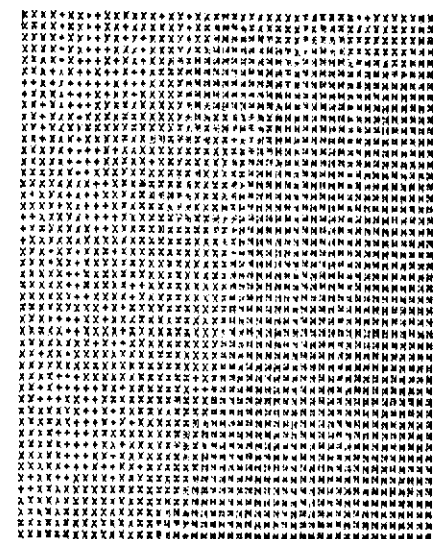
DATA RANGE	POINTE MOUILLEE		ESTRAL BEACH		LA PLAISANCE BAY	
	NUMBER POINTS	PERCENT	NUMBER POINTS	PERCENT	NUMBER POINTS	PERCENT
000-005	257	13.3	509	26.3	1140	51.6
006-010	259	13.4	258	13.3	101	4.6
011-016	308	15.9	305	15.8	249	11.3
017-021	866	44.8	658	34.0	547	24.8
022-026	21	1.1	1	0.0	0	0.0
027-031	214	11.1	204	10.6	172	7.8
032-037	6	0.3	0	0.0	0	0.0
038-042	1	0.0	0	0.0	0	0.0
Sum	1932	99.9	1935	100.0	2200	100.1



(a) Pointe Mouillee



(b) Estral Beach



(c) La Plaisance Bay

FIGURE 24. DIGITAL PRINT-OUT OF LEVEL SLICINGS, DATA DIVIDED INTO EIGHT LINEAR GRAY LEVELS. ERTS-1 Band 7, Scene 1265-15480. Compare to Figure 23.

- b) A second approach is to play the tapes onto a video display and have an operator identify areas of known ground covers. Using several similar surfaces as training sets, a signature for that surface and for that particular data can be constructed and used to determine all similar surfaces in the scene being studied. From this, it is a trivial problem to determine other parameters of the selected ground cover (percentage of cover in the entire scene, location of this cover, etc.).
- c) The third approach varies from the previous two in that the percentage of a scene covered with a given type of surface is known beforehand. But, neither the location nor the signature are very accurately known. The one assumption which must be made in this case is that the several scenes are listed so that the progression of response to the remote sensor is in only one direction. That is, in the case under study, the progression from "open water," "flooded land," "wet land," and "others" is progressively from dark to light tone on the Band 7 image.

The data needed to accomplish the third approach to level-slicing of ERTS-1 tapes are available for the three coastal areas of Monroe County (Table 10). Also, the several categories used for classification of the land surface are in the required (i.e., progressively lighter) sequence.

Consequently, these three study sites (Pointe Mouillee, Estral Beach, and La Plaisance Bay) were studied using this third approach, and the resulting digital maps are presented in Figure 26. Thus, for the Pointe Mouillee (IR interpretation) in Table 10, we note that the darkest areas (66%) of the image are classed as "open water," the next (15%) are classed as "wet" and the highest (brightest) areas (19%) are categorized as "other." The category "built-up" was neglected because it comprised a negligible portion of the area studied. For the other two sites (Estral Beach and La Plaisance Bay) this category was included in the computer classifications.

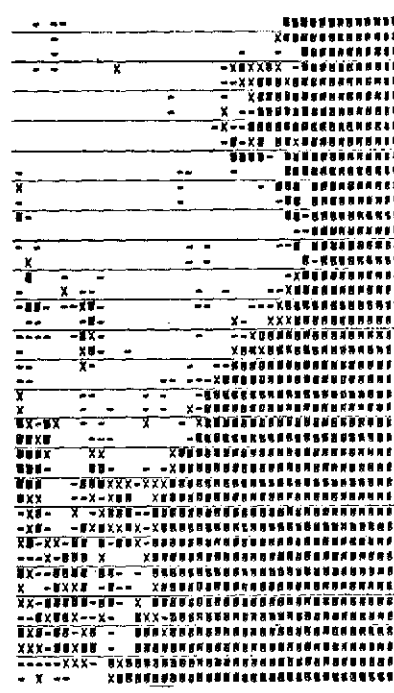
Two problems may be solved using this rather crude digital analysis of these data. The first is to determine the accuracy with which the signatures (i.e., the data range) may be determined, and the second is to assess the accuracy of the location of the particular features which have been identified.

From Table 12 we note that the data ranges for open water were quite close, at least for two of the three study sites. Obviously these figures are fairly crude and there is some variance in the signatures for open water determined for each of the several study sites. Presumably, the data changes for the open water signatures would be reduced or brought into closer congruence had the original data been divided into more categories, say 20 rather than eight or ten. It is interesting to note, however, that the Pointe Mouillee and Estral Beach study areas are fairly comparable with respect to the "open water" signatures and that



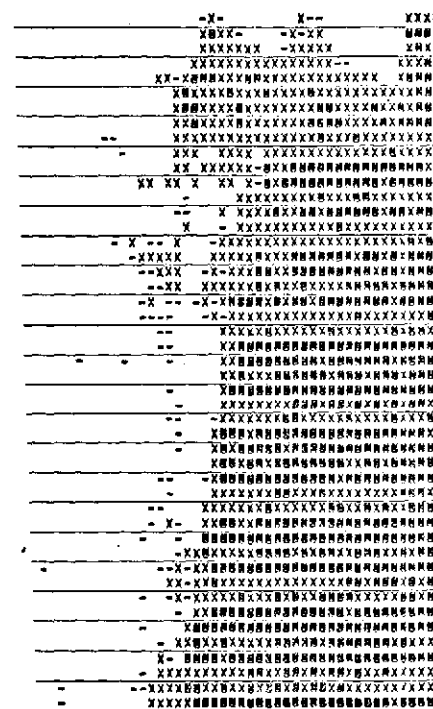
SYMBOL	DATA RANGE	NO. OF ELEMENTS
■	001 017	1176
■	018 019	385
■	020 042	371

(a) Pointe Mouillee



SYMBOL	DATA RANGE	NO. OF ELEMENTS
■	001 014	959
X	015 015	098
■	016 016	171
■	017 027	707

(b) Estral Beach



SYMBOL	DATA RANGE	NO. OF ELEMENTS
■	001 002	638
X	003 010	605
■	011 012	084
■	013 026	882

(c) La Plaisance Bay

FIGURE 26. DIGITAL PRINT-OUT OF LEVEL SLICINGS, USING THE "PERCENTAGE AREA" METHOD. ERTS-1 Band 7, Scene 1265-15480. Based on data presented in Table 10.

TABLE 12. DATA RANGES FROM ERTS-1 (CCT-MSS7) FOR OPEN WATER
FOR THREE COASTAL AREAS

AREA	PERCENT OPEN WATER (Table 10)	DATA RANGE CORRESPONDING TO THIS PERCENT	
		TABLE 11a	TABLE 11a
POINTE MOUILLEE	66%	016-018	016-021
ESTRAL BEACH	50%	014-015	011-016
LA PLAISANCE BAY	46%	003-003	000-005

the La Plaisance Bay area varies widely from the other two. The tone of the open water for this latter area is actually darker (i.e., lower on the data range) because Estral Beach and Pointe Mouillee have contrails overlying them.

Two additional items with respect to data range must also be pointed out:

- a) In the three areas in which the percent-area method was used, only the data ranges of that particular area were studied. Hence, of the full range of data (000-042) only approximately one half (000-027 for Estral Beach and 000-026 for La Plaisance Bay) was used.
- b) The program used to study the data and produce the gray level maps (Fig. 26) is written so that the first division of the data could contain less than or equal to the number of data cells (in percent) for the darkest portion of the data set. For La Plaisance Bay, for example, the amount of open water is listed (Table 10) as being the lowest 46% of the data range for that area. Consequently, the program used determined the data range for those points containing the darkest 46% of the total number of data cells (in this case, 2209). We note (Fig. 26) that the lowest portion of the La Plaisance Bay data range (000-002) contains 638 data points, or 28.6% of the total 2209 data points within the study area. Because the increments for the data (from Table 10) were 46%, 11%, 7% and 36%, and because the addition of the next range of data (003-010) would add another 605 data points (Fig. 26c), the summation of all data points in the data range of 000-010 would result in a total of 1243 data points being classed as open water. This would have meant that the "open water" category would contain 56.3% of the data points and would have been an over-evaluation of the data range. The darker portion of the second data range (that is, data range value 003) contains over 17.4% (i.e., 46.0 - 28.6%) of the data points, and consequently, it can be stated with high confidence that open water, for the La Plaisance Bay area, is essentially within the data range of 000-003. It is thus possible to determine the signature of water for La Plaisance Bay more precisely than for the other two scenes. This is partly because of the nature of the program used to define the gray levels in this study and because the water has a very low reflection, relative to the other study scenes.

This is, admittedly, a rather round-about way to obtain a signature for a given type of ground cover. Nonetheless, it may warrant more detailed examination when, for example, it is possible to determine the area of coverage of forests, lakes, snowfields, etc., for a given area, or when one knows that a given county has a certain portion planted in wheat, corn or other crops. The method is rather crude and lacks the sophistication which is often demanded for more rigorous scientific analysis and study. However, it serves the purpose of the studies

in this report, which was to design some quick and inexpensive methods which may be used by local government organizations or similar groups in need of remote-sensing analysis for near real-time studies.

A point-by-point or random point comparison of the two interpretations of ERTS-1 data (Figs. 23 and 26) was not conducted to determine the accuracy of the location of the open water areas. It is clear however, that the general patterns on the "Percentage Area" maps, in all three cases, follow the pattern displayed for the open water in the (basic) IR interpretations in Figure 23. For Pointe Mouillee, the dikes and many of the smaller islands were often missed in both the visual and the percentage area CCT methods of analysis of Band 7. The separation of "open water" from "flooded land" (and/or wet lands?) was not as clearly demonstrated on the CCT analysis as it was on the visual analysis and indeed, except for the large area in the northern section of the Pointe Mouillee area, open waters are still generally poorly defined for the whole area. The opposite is true for the Estral Beach and the La Plaisance Bay study areas where large portions of the sites classed as "other" are equally well defined on both the percentage area and the visual methods of data analysis.

The two sites in which the built-up category was used, the Band 7 percentage area analysis was of little use, for indeed, the data cells classed as "built-up" are scattered along both the coast and in the inland areas in both study cases. Interestingly, there was little confusion concerning the open water and the built-up categories for either of the two southern study sites.

For Estral Beach the percentage area method correctly identified most of the southern portion of the study site as flooded, or as wetlands, but for La Plaisance Bay, this identification was only poorly made.

When the comparison of the ERTS-1 visual and percentage area methods of analysis are made, it is qualitatively determined that the two are approximately the same. The problems of the increase of accuracy (compared to the IR photography) of the interpretations of the ERTS-1 Band 7 data relate more to the resolution of the system and the size of the data areas which are being studied. For the original ERTS-1 imagery presented to the investigator, the scale was approximately 1:1,000,000. This was increased to a scale of 1:50,000 for the visual interpretations, and enlargement of 20 \times , which is considered to be about the greatest amount of enlargement that can be made on the ERTS-1 imagery. (The enlargements were made from the 9.5 \times 9.5-inch negatives provided by NASA-Goddard.) For the CCT analysis, the individual data cells, representing a resolution element of approximately 90 \times 90 m were used. Because only Band 7 was used in both of these analyses, the accuracy of interpretation is probably reduced since other spectral information included in the other three bands was ignored. A reference to the earlier data (Fig. 3) presented in the case of the ice and snow studies, speaks

strongly to the need to consider all spectral bands when interpreting the ERTS-1 data. To use all of these data would require a more extensive program and therefore, more time for the analysis. This would, to a degree, subvert the purpose of these efforts - that is, to identify some quick, inexpensive and relatively accurate methods of identifying flooding and flooded coastal areas using remote-sensing data.

4.4 CONCLUSIONS TO FLOODING STUDIES

The studies of the Monroe County, Michigan flooding of April 1973 using three different remote sensors has led to several conclusions. When using the black and white IR aerial photography as a basic data set for comparison, the X(HH) data from SLAR was the single best sensor for obtaining similar data. This is because the resolution of the SLAR is fairly high (30×30 ft) and therefore approximately one order of magnitude greater than the resolution of ERTS-1. The other SLAR data [X(HV), L(HV), L(HH)] contributed to the interpretation primarily in making the finer distinctions between wet lands, marshes and the like.

Built-up areas were not visible on the ERTS-1 Band 7 imagery primarily because, in the study areas, they were both flooded and surrounded by open water or relatively continuous vegetation. Hence, these built-up areas would be classed as suburban residential, and were not congested as would be a large town or city. In that respect, the comments concerning the built-up classification are probably applicable only to small rural and primarily residential areas. However, as mentioned, when flooded they were classed as "flooded" and not distinguished from other flooded lands on the ERTS-1 Band 7 imagery. The SLAR data, on the other hand, were extremely useful for identifying the built-up areas, even though they were not also identified as "flooded," "wet" or "other." Consequently, these two sensors used in concert from orbital heights could provide data to relief organizations which would identify the flooded areas in addition to those areas which were also built up.

The use of the ERTS-1 CCT has led to a series of very sophisticated algorithms for the analysis of a wide variety of earth surfaces. Normally either the signature of the surface or training sets of data are needed to identify specific types of earth surfaces. It has been demonstrated in this work that in areas where the percentage of the site covered by a given surface is known, and if it is possible to place this surface accurately in the gray spectrum for any given ERTS-1 Band, then the CCT can easily and simply be used for identifying the location of that particular earth surface. This does allow the use of CCT techniques - and therefore the quick, but relatively crude analysis of satellite data.

CONCLUSIONS AND RECOMMENDATIONS

The conclusions resulting from this work comparing the relative usefulness of two remote sensors (ERTS-1 and SLAR), both of which are operative from orbital altitudes, are listed below. It must be noted that the resolution of the data used in this study is the same as would be obtainable from orbital altitudes of these two sensors although the SLAR was, for this study, actually an airborne system flying at relatively low altitudes (10,000 ft). Low altitude airborne black and white infrared photography was used primarily as a control or surrogate ground-truth source for the studies of flooding in Monroe County, Michigan.

The conclusions are:

- (1) For the visual analysis of ERTS-1 imagery, a basic set of radiometric signatures are easily and cheaply obtainable by the researcher working in his own field area. Such data may be collected at the time of the satellite pass, requires a minimum of manipulation and quickly provides necessary guidance for visual interpretation of the ERTS-1 imagery.
- (2) For studies of lake ice, ERTS-1 Band 7 has proven to be the best suited for identifying open water and open-pack ice. As the amount of open water in the scene decreases, or as the amount of free water in the snow decreases, there is a decided preference for using the shorter wavelengths for identification. However, in cases where the spectral response curve is essentially flat for all wavelengths (e.g., snow), all four ERTS-1 bands are necessary for adequate identification.
- (3) The study of the electrical properties of the ice and snow pack are fruitful in that the low dielectric constant (ϵ_1) and low loss tangent ($\tan \delta$) indicate that energy penetration can be considerable in the cases of the ice and snow having no free water. This expands the information available beyond that obtained from ERTS-1 and comparison of the two data sets should yield considerable additional information about the subject material.
- (4) SLAR data apparently gives information concerning the internal structure of the snow and ice (as opposed to the surface information which is available from ERTS-1), and consequently supplements the ERTS-1 data.
- (5) For the monitoring of ice, all four ERTS-1 bands are useful and generally necessary. There is some argument for the finer division of the ERTS-1 bands (i.e., finer spectral resolution) especially in the longer wavelengths where the spectral response curve rapidly decreases with increasing wavelength. No conclusion may be drawn concerning the SLAR imagery for ice because there were no data available at the time this study was being conducted.

- (6) The measurement of floods and flooding areas (using ERTS-1 Band 7 only) is quite promising. A major problem is the identification of the small land and water areas which tend to be obscured within the resolution element of the system.
- (7) Band 7 of ERTS-1 did not allow the detection of the several small towns in the Monroe County study site. Alternatively, those urban sites which were flooded, were easily identified as flooded. The SLAR detected the same built-up areas, but it was not always possible to identify them as flooded on the available imagery. By combining the two systems, the identification of the flooded towns was easily and accurately achieved using the photo-interpretation approach. The near simultaneous and near-real time availability of data from the two sensors could be extremely useful for guidance of flooding and post-flooding rescue and disaster relief operations.
- (8) Because the resolution cell of ERTS-1 is relatively large (approximately 300 ft) it appears rational and necessary to supplement this system with a fine resolution active microwave imaging system such as synthetic aperture SLAR. This would allow the continual monitoring of some sites through most weather conditions, and the collection of data over a wide portion of the electromagnetic spectrum during periods of high atmospheric attenuation in the visible portion of the spectrum.
- (9) In the case of floods, it appears that the ERTS-1 Band 7 is the single best band for monitoring both water and moist and saturated soils. For these studies, SLAR X-Band (HH, HV) gave the vast majority of the data used in the image interpretation.
- (10) It is also concluded that the near real-time availability of these data should be strongly encouraged. The data need not be confined to the same level of technological sophistication. For the examples used herein, near real-time (less than 12 hours) data dissemination is mandatory if a goal is the inclusion of numerous smaller organizations in the utilization of the data for disaster and operational purposes.
- (11) It is a relatively easy task to use the ERTS-1 CCT for identifying the location of a given ground surface if the following two items are known: (a) the location of the radiometric response of that surface in the continuum of the gray scale for the study scene and (b) the percentage of the study area which is covered with that particular ground surface.
- (12) The combination of the SLAR and ERTS-1 data are definitely complementary to one another, as demonstrated in the case of the built-up and flooded areas. SLAR was instrumental in identifying these areas as built-up, whereas ERTS-1 Band 7 were necessary to identify the flooded condition.

On the whole, past experience has indicated that small governmental units and those organizations lacking relatively large staffs or budgets, have been excluded from the use of much of the remote sensing data which are available. Part of this situation has resulted from the distribution of the data, but the concern in this study has related primarily to the types of analysis which have been conducted. The emphasis in this report is the need for the development of simple, inexpensive and relatively quick methods for analyses of remote-sensing data from SLAR and ERTS-1. For the former, only visual analysis, in the photo interpretation mode is presently possible, primarily because technology has not yet developed the automatic recognition and classification capabilities. Nonetheless, these data can be quickly analyzed using photo interpretation, and because the data are available at a very high resolution (30×30 ft) from orbital altitudes, they hold a great deal of promise for use by all types of organizations wishing to obtain quick information about some dynamic portion of the earth's surface. It is strongly recommended that SLAR data be collected with increasing vigor, and equally vigorously distributed and made available to earth scientists for analysis and study. This all-weather sensor can overcome many of the data collection problems experienced by ERTS-1 (specifically the problem of cloud and weather penetration) and provide people with near real-time data.

The ERTS-1 sensor, although of a much lower resolution than the SLAR, provides a different type of information and the two systems are strongly complementary. Consequently, it is suggested that an increased effort be made to study the data from a set of sensors covering a broad range of the electromagnetic spectrum; in this case the visible, near visible and several portions (3 and 26 cm) of the microwave were used. This is possibly not the best combination for obtaining earth science data, and continued efforts should be made along these lines to identify the contribution of each sensor for the particular earth science problems at hand.

Finally, increased efforts should be made to develop relatively simple, small, portable and inexpensive instruments which will aid the scientist in the analysis of the remotely-sensed data. Field instruments, such as the Q-meter or the Bendix RMP1 which were used in this study are indicative of the types of instrumentation which are considered to warrant an increased effort. The use of data so collected, and the introduction of these ground-truth data for the automatic analysis of the remotely-sensed data should be continually encouraged.

C-15

Appendix

PRECEDING PAGE BLANK NOT FILMED

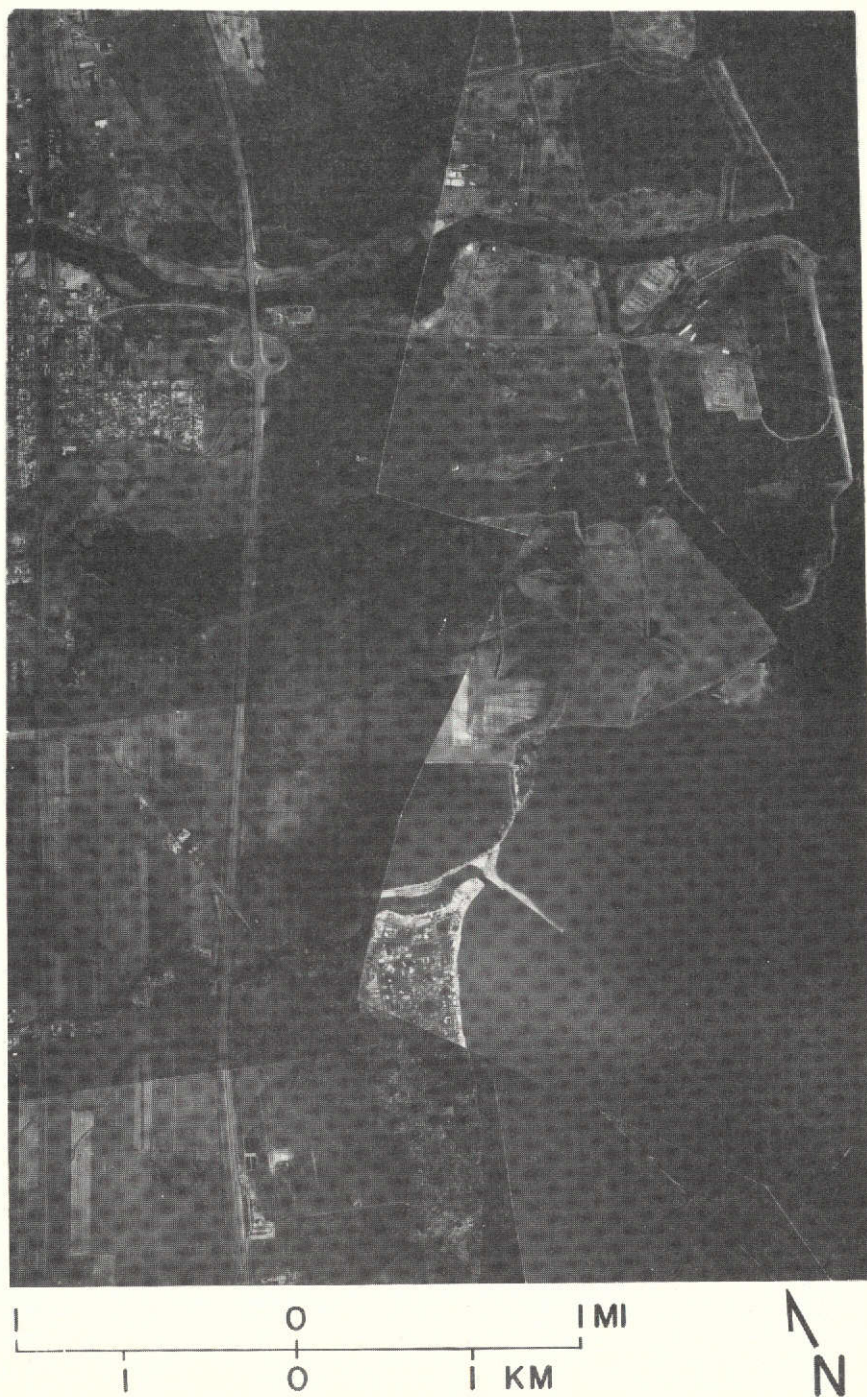


FIGURE A-1. IR PHOTOGRAPHY, MONROE COUNTY, MICHIGAN, 11 APRIL 1973



FIGURE A-2. IR PHOTOGRAPHY, MONROE COUNTY, MICHIGAN, 11 APRIL 1973

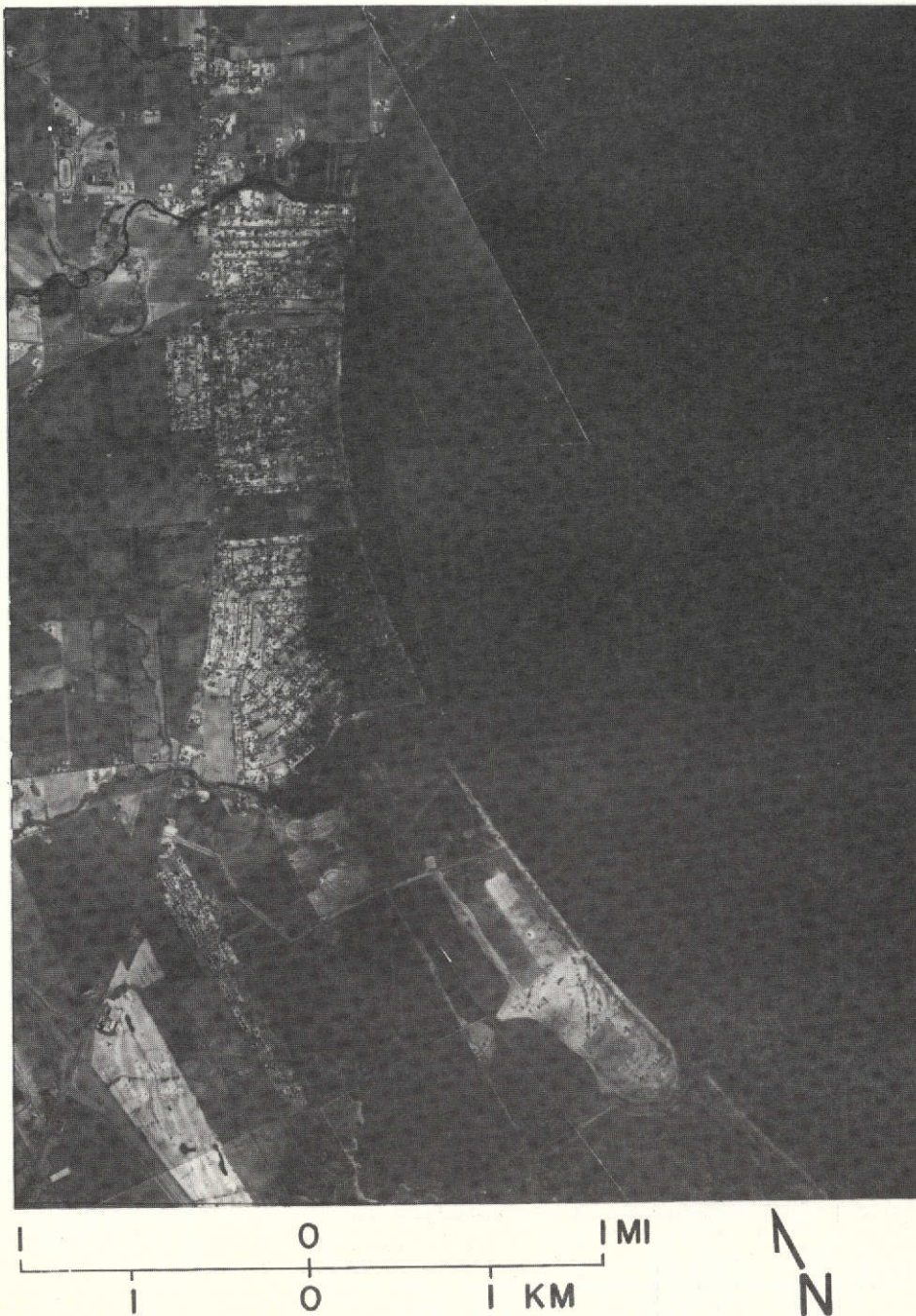


FIGURE A-3. IR PHOTOGRAPHY, MONROE COUNTY, MICHIGAN, 11 APRIL 1973



FIGURE A-4. IR PHOTOGRAPHY, MONROE COUNTY, MICHIGAN, 11 APRIL 1973

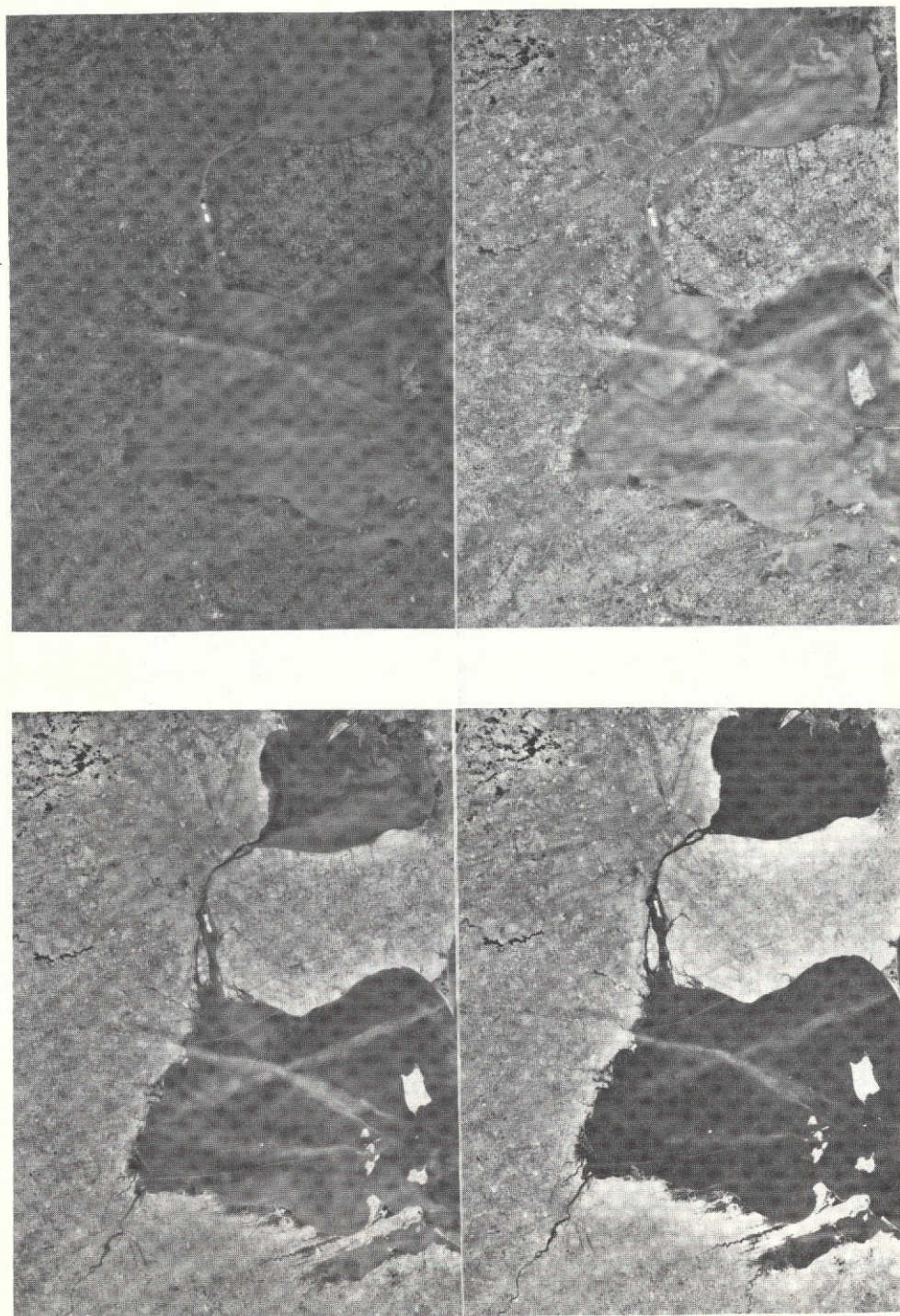
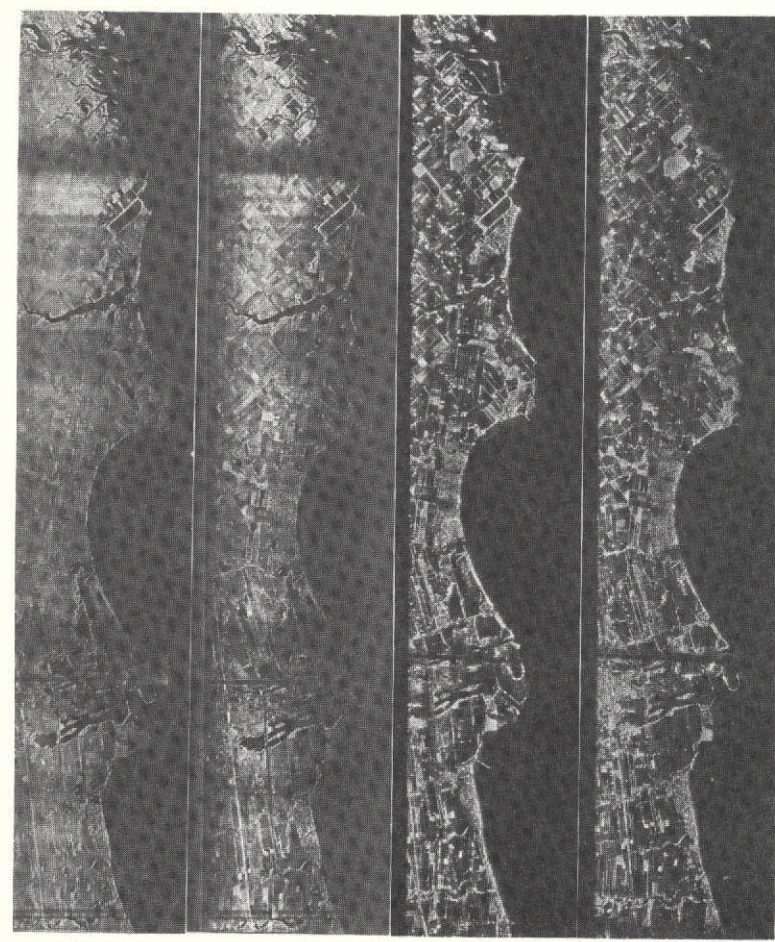


FIGURE A-5. ERTS-1 IMAGERY, MONROE COUNTY,
MICHIGAN, 14 APRIL 1973. Scene 1265-14580.
Top: Band 4; Band 5. Bottom: Band 6; Band 7.

SLAR IMAGERY 05APR73



X(HH) X(HV) L(HH) L(HV)

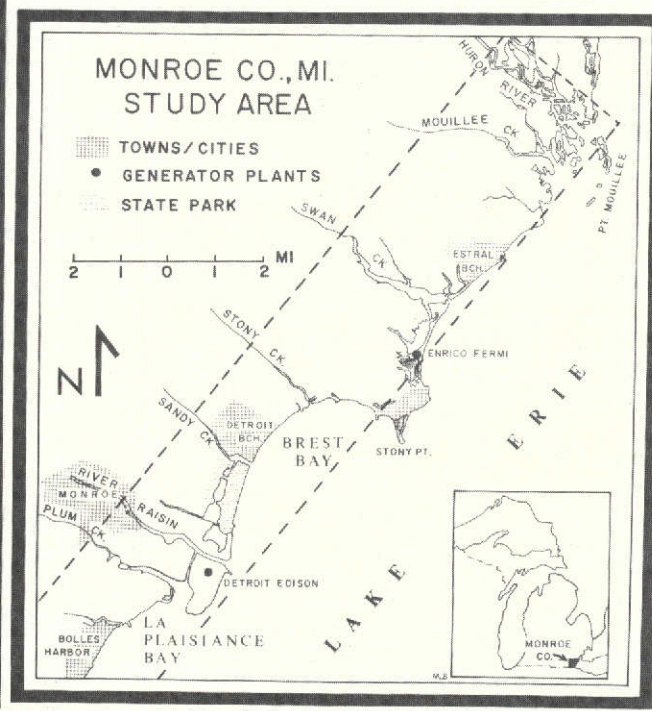


FIGURE A-6

REFERENCES

- Anderson, R. R., ERTS-1 Data User Investigation of Wetland Ecology, Type I Progress Report No. 4, February 1973. (Available: NTIS #E73-10288)
- Anikouchine, W. A., Acquisition and Analysis of Coastal Ground-Truth Data for Correlation with ERTS-A Imagery, Type II Progress Report, 2 October 1972 - 2 April 1973, Oceanographic Services Inc., Santa Barbara. (Available: NTIS #E73-10482)
- Armstrong, T., B. Roberts and C. Swinthinbank, Illustrated Glossary of Snow and Ice, Scott Polar Research Institute, Cambridge, U.K., 1969.
- Bader, H. et al., Snow and Its Metamorphosis (Der Schnee und seine Metamorphose, Beitrage zur Geologie der Schweiz, Geotechnische Serie, Hydrologie, Lieferung 3), Translation No. 14, USA SIPRE, Wilmette, Illinois, 1954.
- Barnes, J. C. and C. J. Bowley, "Use of ERTS Data for Mapping Snow Cover in the Western United States," Symposium on Significant Results Obtained from the Earth Resources Technology Satellite, Vol. 1, SP-327, NASA, Washington, D. C., 1973(a), pp. 855-862. (Available: NTIS #E73-10057)
- Barnes, J. C. and C. J. Bowley, "Use of ERTS Data for Mapping Arctic Sea Ice," Symposium on Significant Results Obtained from the Earth Resources Technology Satellite, Vol. 1, SP-327, NASA, Washington, D. C., 1973(b), pp. 1377-1384.
- Beckman, P., Dipolarization of Electromagnetic Waves, The Golem Press, Boulder, Colorado, 1968.
- Bensen, L. A. and F. A. Waltz, Monitoring Flood Damage with Satellite Imagery, ERTS-1 Interim Report, Remote Sensing Institute, South Dakota State University, Brookings, March, 1973. (Available: NTIS #N73-21361)
- Benson, A. S. et al., "Ground Data Collection and Use," Photogrammetric Engineering, Vol. 37, 1971, pp. 1159-1166.
- Berkowitz, R. S., Modern Radar: Analysis, Evaluation and System Design, J. Wiley and Sons, New York, 1966.
- Boyce, D. E., "The 1972-1973 Great Lakes Ice Season," Mariners Weather Log, Vol. 17, No. 5, September 1973, pp. 285-289.
- Brazel, A. J. and D. W. Phillips, "November 1972 Floods on the Lower Great Lakes," Weatherwise, Vol. 27, No. 2, April, 1974, pp. 56-62.
- Brown, W. E., "Radar Studies of the Earth," Proceedings of the Institute of Electronics and Electrical Engineers, Vol. 57, April, 1974, pp. 612-620.
- Bryan, M. L., Radar Remote Sensing for Geosciences: An Annotated and Tutorial Bibliography, Report No. 193500-1-B, Environmental Institute of Michigan, Ann Arbor, 1973.
- Bryan, M. L. and R. W. Larson, "Interpretation of SLAR Imagery of Ice in Whitefish Bay," Michigan, presented at the 17th Annual Conference of the International Association for Great Lakes Research, Hamilton, Ontario, Canada, 12-14 August, 1974.
- Carlson, R. F., "Break-Up Characteristics of Chena River Basin," Second Semi-Annual Technical Report, NASA Contract NAS5-21833, Institute of Water Resources, University of Alaska, Fairbanks, July, 1973. (Available: NTIS #E73-10903)
- Cosgriff, R. L. et al., Terrain Scattering Properties for Sensor System Design, Columbus, Ohio. The Ohio State U. Eng. Exp. Sta. Bull., Vol. 29, No. 3, May, 1960, 118 pp.

- Crandall, C. J., "Radar Mapping in Panama," *Photogrammetric Engineering*, Vol. 35, July, 1969, pp. 641-646.
- Cutrona, L. J., et al., "On the Application of Coherent Optical Processing Techniques to Synthetic-Aperture Radar," *Proceedings of the Institute of Electrical and Electronic Engineers*, Vol. 54, July, 1966, pp. 1026-1032.
- Dellwig, L. F. and R. K. Moore, "The Geological Value of Simultaneously Produced Like- and Cross-Polarized Radar Imagery," *Journal of Geophysical Research*, Vol. 71, July, 1966, pp. 3597-3601.
- Evans, S., "Dielectric Properties of Ice and Snow: A Review," *Journal of Glaciology*, Vol. 5, 1965, pp. 773-792.
- Gray, D. M., *Handbook on the Principles of Hydrology*, Ottawa National Research Council of Canada, Canadian National Committee for the Hydrologic Decade, Ottawa, Ontario, 1970.
- Gribben, H. R., et al., "Side-Looking Radar: State of the Art," *World Cartography*, Vol. 11, 1971, pp. 16-32.
- Guinard, N. W., "Remote Sensing of Ocean Effects with Radar," in Lomax, J.B. (ed.), *Propagation Limitations in Remote Sensing*, AGARD Conference Proceedings, No. 90, 1971, pp. 15-1 to 15-12. (Available: NTIS #AD 736 309).
- Hackman, R. J., "Geological Evaluation of Radar Imagery in Southern Utah," Professional Paper 575D, U. S. Geological Survey, 1967, pp. 135-142.
- Hagfors, T., "A Study of the Dipolarization of Lunar Radar Echos," *Radio Science*, Vol. 2, May, 1967, pp. 445-465.
- Hoekstra, P. and D. Spangle, "Radar Cross-Section Measurements of Snow and Ice," Technical Report 235, U. S. Army Corps of Engineers, CRREL, Hanover, N. H., November, 1972.
- Horvath, R. and W. L. Brown, *Multispectral Radiative Characteristics of Arctic Sea Ice and Tundra*, Report No. 27980-2-F, Willow Run Laboratories of the Institute of Science and Technology, University of Michigan, Ann Arbor, July, 1971. (Prepared for The Arctic Institute of North America, Agreement ONR-426)
- Innes, R. B., "An Interpreter's Perspective on Modern Airborne Radar Imagery," Report No. 4864-18-X, *Proceedings of the Fifth Symposium on Remote Sensing of Environment*, Willow Run Laboratories of the Institute of Science and Technology, The University of Michigan, Ann Arbor, 1968, pp. 107-122.
- Johnson, J. D. and L. D. Farmer, "Use of Side-Looking Air-Borne Radar for Sea Ice Information," *Journal of Geophysical Research*, Vol. 76, March, 1971, pp. 2138-2155.
- Kodak, *Kodak Data for Aerial Photography*, Pub. #M-29, Third Ed., Eastman Kodak Co., Rochester, N. Y., 1971.
- Laprade, G. L., "An Analytical and Experimental Study of Stereo for Radar," *Photogrammetric Engineering*, Vol. 29, March, 1963, pp. 294-300.
- Larowe, B. T. et al., *Fine Resolution Radar Investigation of Great Lakes Ice Cover*, Report No. 1900-1-F, Willow Run Laboratories of the Institute of Science and Technology, The University of Michigan, Ann Arbor, 1971.
- Larson, R. W. et al., *Results Obtained from The University of Michigan Hologram Radar*, Report No. 10259-1-X, *Proceedings of the Seventh International Symposium on Remote Sensing of Environment*, Willow Run Laboratories of the Institute of Science and Technology, The University of Michigan, Ann Arbor, 1971.
- Lind, A. O., *Environmental Study of ERTS-1 Imagery of Lake Champlain Basin and Vermont*, ERTS-1 Type II Report, Department of Geography, University of Vermont, 1972. (Available: NTIS #E72-10282)

- Lind, A. O., Survey of Lake Flooding from ERTS-1, ERTS-1 Type I Report, Department of Geography, University of Vermont, 1973(a). (Available: NTIS #E73-10771)
- Lind, A. O., Ice Development on Lake Champlain, ERTS-1 Report, Department of Geography, University of Vermont, 1973(b). (Available: NTIS #E73-10806)
- Lundien, J. R., "Remote Measurement of Dielectric Constants and Conductivity for Soils," Proceedings of the Institute of Electrical and Electronic Engineers, Vol. 5, April, 1965, pp. 420-421.
- Lundien, J. R., "Terrain Analysis by Electromagnetic Means," Report No. AEWES-TR-3-693-5, Army Eng. Waterways Experiment Station, Vicksburg, Miss., February, 1971. (Available: NTIS #AD 881 799)
- MacDonald, H. C. and W. P. Waite, "Soil Moisture Detection with Imaging Radars," Water Resources Research, Vol. 7, February, 1971, pp. 100-110.
- Marshall, E. W., Air Photo Interpretation of Great Lakes Ice Features, Special Report No. 25, Great Lakes Research, Institute of Science and Technology, The University of Michigan, Ann Arbor, 1966.
- McCoy, R. M., "Drainage Network Analysis with K-Band Radar Imagery," Geographical Review, Vol. 59, October, 1969, pp. 493-512.
- Meier, M. F. and A. T. Edgerton, "Emission Characteristics of Snow and Ice in the Microwave Region," Third Annual Earth Resources Program Review, Vol. 111, NASA, MSC, Houston, 1970, pp. 51-1 to 51-14. (Available: NTIS #N72-12294)
- Meier, M. F., "Evaluation of ERTS Imagery for Mapping and Detection of Changes of Snow-cover on Land and on Glaciers," Report No. SP-327, Symposium on Significant Results Obtained from the Earth Resources Technology Satellite, Vol. 1, NASA, Washington, D. C., 1973, pp. 863-875.
- Moore, R. K., Radar Return from the Ground, Engineering Bulletin #59, University of Kansas, Lawrence, 1969, 87 pp.
- Noble, V. E. et al., "Some Aspects of Remote Sensing as Applied to Oceanography," Proceedings of the Institute of Electrical and Electronic Engineers, Vol. 57, April, 1969, pp. 594-604.
- Porcello, L. J. and R. A. Rendleman, "Multiple Imaging Radar," 4th Annual Earth Resources Program Review, Vol. 11, University Programs, NASA, MSC, Houston, January, 1972, pp. 35-1 to 35-18.
- Ramo, S. and J. R. Whinnery, Field and Waves in Modern Radio, J. Wiley and Son, Inc., N. Y., 1958, Chapter 7.
- Reeves, R. G., "Structural Geologic Interpretations from Radar Imagery," Geological Society of America Bulletin, Vol. 80, November, 1969, pp. 2159-2164.
- Rogers, R. H. and K. Peacock, "A Technique for Correcting ERTS Data for Solar and Atmospheric Effects," Report No. SP-327, Symposium on Significant Results Obtained from the Earth Resources Technology Satellite, Vol. 1, NASA, Washington, D. C., 1973, pp. 1115-1122.
- Rosenfeld, A., Picture Processing By Computer, N. Y. Academic Press, 1969.
- Rouse, J. W., Jr., "Arctic Ice Type Identification by Radar," Proceedings of the Institute of Electrical and Electronic Engineers, Vol. 57, April, 1969, pp. 605-611.
- Rouse, J. W., Jr. and S. Siter, "ERTS Experiments," IEEE Transactions on Geoscience Electronics, Vol. GE-11, No. 1, January, 1974, pp. 3-77.
- Rydstrom, H. O., "Interpreting Local Geology from Radar Imagery," Geological Society of America Bulletin, Vol. 78, March, 1967, pp. 429-436.

22

- Sattinger, I., et al., Remote Sensing in Michigan for Land Resource Management: Annual Report No. 190800-2-F, Environmental Research Institute of Michigan, Ann Arbor, 1972.
- Schultz, C. H., et al., "Radar Backscattering Data for Surfaces of Geological Interest," Ohio State University, Columbus, Ohio, December 1969. (Available: NTIS #N70-28539)
- Verger, F., Marshes and Turbid Waters on the French Atlantic Litoral, ERTS-1 Type I Report, Centre National D'Etudes Spatiales, Paris, 1972. (Available: NTIS #E72-10251)
- Waite, W. P. and H. C. MacDonald, "Snowfield Mapping with K-Band Radar," Remote Sensing of Environment, Vol. 1, March, 1970, pp. 143-150.
- Walters, R. L., Radar Bibliography for Geoscientists, Report No. 61-30, University of Kansas Center for Research Inc., Lawrence, 1968. (Available: NTIS #N69-30303)
- Wendler, G., "Sea Ice Observations by Means of Satellites," J. of Geophys. Res., Vol. 78, No. 9, March 20, 1973, pp. 1427-1444.
- Wendler, G. et al., "Break-Up Characteristics of the Chena River Watershed, Central Alaska," Interim Scientific Report, NASA Contract NAS5-21833, November, 1973. (Available: NTIS #E74-10151)
- Wilson, J. E., "Ground Truth Procedures for Aiding Interpretation of Remote Sensor Data," Proceedings of the 34th Annual Meeting, American Society of Photogrammetry, Washington, D. C., March, 1968, pp. 365-375.
- Wilson, J. T., J. H. Zumberge and E. W. Marshall, A Study of Ice on an Inland Lake, SIPRE Report No. 5, Part 1, U. S. Army Corps of Engineers, Wilmette, Illinois, 1954.
- Wing, R. S., "Structural Analysis from Radar Imagery of the Eastern Panamanian Isthmus, Part 1," Modern Geology, Vol. 2, February, 1971, pp. 1-21.

REPORTS AND PAPERS PREPARED UNDER THIS CONTRACT

- Bryan, M. L., "The Utility of Imaging Radars for the Study of Lake Ice," International Association Hydrological Sciences Pub. No. 107, The Role of Snow and Ice in Hydrology, Symposium, Canadian National Committee for the International Hydrological Decade, 1973(a), pp. 1339-1349.
- Bryan, M. L., "Using Imaging Radars for the Study of Lake Ice Features in the Upper Great Lakes," Paper presented to Association of American Geographers, East Lakes Division, Indiana, Pennsylvania, 5 October 1972.
- Bryan, M. L., and R. W. Larson, "Application of Dielectric Constant Measurements to Radar Imagery Interpretation," in F. Shahrokhi, (ed), Remote Sensing of Earth Resources, Vol. II, Conference on Earth Resources Observations and Information Analysis Systems, University of Tennessee, Tullahoma, 1973, pp. 529-547. (Available: NTIS #E73-10429)
- Bryan, M. L., Multi-Frequency Simultaneous Radar Imagery, Project Report No. 193300-26-X, Environmental Research Institute of Michigan, Ann Arbor, 1973(b). (Available: NTIS #N73-11119)
- Bryan, M. L., Fresh-Water Ice Interpretation from ERTS-1 Imagery, Report No. 193300-24-L, Environmental Research Institute of Michigan, Ann Arbor, 1973(c). (Available: NTIS #E73-11129)
- Bryan, M. L., "Radiometric Ground Truth and Interpretation of ERTS-1 Data of Freshwater Ice," Presented to Association of American Geographers, 70th Annual Convention, Seattle, Washington, 2 May 1974.

Bimonthly (Type I) Reports

(These reports include contributions from 10 tasks of Contract NAS5-21783)

- Thomson, F. J. et al., First Bimonthly Report for Period Covering 1 July - 31 August 1972, Report No. 11229-2-L, Environmental Research Institute of Michigan, Ann Arbor, 1972(a).
- Thomson, F. J. et al., Second Bimonthly Report for Period Covering 1 September - 31 October 1972, Report No. 11229-10-L, Environmental Research Institute of Michigan, Ann Arbor, 1972(b).
- Thomson, F. J., et al., Third Bimonthly Report for Period Covering 1 November - 31 December 1972, Environmental Research Institute of Michigan, Ann Arbor, 1973(a).
- Thomson, F. J., et al., Fourth Bimonthly Report for Period Covering 1 January - 28 February 1973, Report No. 193300-6-L, Environmental Research Institute of Michigan, Ann Arbor, 1973(b). (Available: NTIS #N73-20349 to N73-20359, #E73-10387 to E73-10397)
- Thomson, F. J., et al., Fifth Bimonthly Report for Period Covering 1 March - 20 April 1973, Report No. 193300-13-L, Environmental Research Institute of Michigan, Ann Arbor, 1973(c).
- Thomson, F. J., et al., Sixth Bimonthly Report for Period Covering 1 July - 31 August 1973, Report No. 193300-24-L, Environmental Research Institute of Michigan, Ann Arbor, 1973(d). (Available: NTIS #E73-11119)
- Thomson, F. J., et al., Seventh Bimonthly Report for Period Covering 1 September - 30 October 1973, Report No. 193300-31-L, Environmental Research Institute of Michigan, Ann Arbor, 1973(e). (Available: NTIS #E74-10097)

Thomson, F. J., et al., Eighth Bimonthly Report for Period Covering 1 January - 28 February 1974, Report No. 193300-41-L, Environmental Research Institute of Michigan, Ann Arbor, 1974(a).

Thomson, F. J., et al., Ninth Bimonthly Report for Period Covering 1 March - 30 April 1974, Report No. 193300-49-L, Environmental Research Institute of Michigan, Ann Arbor, 1974(b).

Semiannual (Type II) Reports

(These reports include contributions from 10 tasks of Contract NAS5-21783)

Thomson, F. J., et al., ERIM Progress Report on Use of ERTS-1 Data: Summary Report of Work on Ten Tasks, 1 July - 31 December 1972, Report No. 193301-1-P, Environmental Research Institute of Michigan, Ann Arbor, 1973(f). (Available: NTIS #N73-17298; #E73-10086)

Thomson, F. J., et al., ERIM Progress Report on Use of ERTS-1 Data: Summary Report of Work on Ten Tasks, 1 January - 30 June 1973, Report No. 193300-16-P, Environmental Research Institute of Michigan, Ann Arbor, 1973(g). (Available: NTIS #E73-10899)

Thomson, F. J., et al., ERIM Progress Report on Use of ERTS-1 Data: Summary Report of Work on Ten Tasks, 1 July - 31 December 1973, Report No. 193300-37-P, Environmental Research Institute of Michigan, Ann Arbor, 1974(c). (Available: NTIS #N74-10301; #E74-10301)



DISTRIBUTION LIST

Goddard Space Flight Center
Greenbelt, Maryland 20771

ATTN: Scientific Investigations Support
Code 902.6

(10)